Hydroacoustic Biomass Estimates of Bathypelagic Groundfish in Georgia Strait, January, February, and April, 1981

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ABSTRACT

Kieser, R. 1983. Hydroacoustic biomass estimates of bathypelagic groundfish in Georgia Strait, January, February, and April, 1981. Can. MS Rep. Fish. Aquat. Sci. 1715: iv + 84 p.

Hydroacoustic echo integration surveys were carried out in the Strait of Georgia to determine the absolute abundance and distribution of Pacific hake (Merluccius productus) and walleye pollock (Theragra chalcogramma). The prespawning and spawning periods of the target species were covered by the cruises in January, February, and April 1981.

Total biomass was estimated as 67, 88, and 112 kt for the three months, respectively. Pacific hake accounted for 73, 86, and 71% of the estimates. Hake, pollock, and dogfish (Squalus acanthias) accounted for almost the entire catches that were made for species identification. The echogram and catches indicated two distinct midwater layers during all surveys. In April, a dense plankton layer was present in the shallow layer.

Key words: Biomass estimation, hydroacoustic, echo integration, Pacific hake (Merluccius productus), Walleye pollock (Theragra chalcogramma).

RÉSUMÉ

Kieser, R. 1983. Hydroacoustic biomass estimates of bathypelagic groundfish in Georgia Strait, January, February, and April, 1981. Can. MS Rep. Fish. Aquat. Sci. 1715: iv + 84 p.

On a mené des levés hydroacoustiques par intégration échographique dans le détroit de Géorgie, dans le but de déterminer l'abondance absolue et la répartition du merlu du Pacifique (Merluccius productus) et de la morue du Pacifique occidental (Theragra chalcogramma). Les périodes de pré-fraie et de fraie ont été étudiées au cours de croisières réalisées en janvier, février et avril 1982.

La biomasse totale a été respectivement évaluée à 67, 88 et 112 kt pour ces trois mois. Le merlu du Pacifique constituait 73, 86 et 71 % des estimations. Le merlu, la morue et l'aiguillat (Squalus acanthias) formaient la plus grande partie des prises effectuées pour l'identification des espèces. Selon l'échogramme et les prises, deux couches mésopélagiques distinctes étaient présentes au cours de tous les levés. En avril, une couche dense de plancton peuplait les plus faibles profondeurs.

Mots-clés: estimation de la biomasse, hydroacoustique, intégration échographique, merlu du Pacifique (Merluccius productus), morue du Pacifique occidental (Theragra chalcogramma)

INTRODUCTION

The Strait of Georgia contains under-exploited stocks of Pacific hake (Merluccius productus) and walleye pollock (Theragra chalcogramma). The hake are smaller than those found in the open ocean, yet can provide a good, marketable product. These stocks are believed to be resident in the Strait of Georgia. Thus, unlike in the open ocean, an opportunity exists to carry out a series of hydroacoustic echo integration surveys that will trace the distribution and movement of these stocks and provide several consecutive biomass estimates that can be compared to each other. It is expected that these biomass estimates should be relatively stable over a period of several months if the stocks are indeed resident and if the fish are available for hydroacoustic assessment throughout this period.

The present work was designed to coincide with a series of swept volume surveys of the major hake and pollock stocks in the Halibut Bank-Point Roberts area (Thompson and McFarlane 1982) and with an extensive ichthyoplankton survey of the main hake and pollock spawning areas in the Strait of Georgia (J. C. Mason pers. comm.). The 'simultaneous' and independent biomass estimates and results from the three sets of surveys will be the subject of a future report.

MATERIALS AND METHODS

A. SURVEY DESIGN

The hydroacoustic surveys were designed to cover the Strait of Georgia (Fig. 1) from Alden Bank (Saturna Island) to Cape Mudge (Quadra Island). Three surveys were executed during 12-23 January, 9-20 February, and 13-24 April, 1981. These times cover the prespawning and spawning period of hake and pollock. During each cruise the entire area was surveyed during daylight hours and, time permitting, during the hours of darkness.

The surveys were made along predetermined parallel transects with a 3 naut mi spacing (Fig. 1). These were designed to cross the range of water depths, resulting in a sample of the various fish habitats. Tracklines proceeded to within 1/2 naut mi of the shore line or 55 m depth. Transects S1 through S45 and N1 through N35 covered the southern and northern half of the Strait of Georgia while SA1 through SA7, M1 through M15 and NA1 through NA13 covered Sabine Channel (NE of Lasqueti Island), Malaspina Strait (NE of Texada Island) and its northern extension respectively.

To test the repeatability of echo integration estimates under the prevailing conditions, three replicate surveys were carried out in Malaspina Strait, off Halibut Bank (Gabriola Island) and off Point Roberts (Fig. 2).

B. TEST FISHING AND BIOLOGICAL SAMPLING

Hydroacoustic surveys require complementary information for species identification. During all three cruises this information was collected using a 434 mesh Engel net, a nylon midwater trawl with 73 m bridles and 3 m^2 Süberkrüb otter boards. The codend had a 2.5 cm mesh liner to retain small fish. The fishing depth and opening of the net was monitored by a 30 kHz Elac net sounder. The fishing gear, its operation and the catches were reported by Barner et al. (1981, 1982).

Approximately one-third of the daytime hours were devoted to test fishing, 21, 12, and 23 sets were made, respectively. The sampling of the catch followed the procedure described by Westrheim (1967, 1976) and Barner et al. (1981). The entire catch was sorted by species into tubs of 45 kg nominal capacity. For small catches all tubs were weighed and the length and sex of each fish determined. Large catches were subsampled. Two tubs from the beginning, middle and end of each sorting were taken, the remaining tubs were counted and discarded. The main sampling effort was directed towards hake, pollock, and dogfish (Squalus acanthias).

The species composition for the first and the last cruise were derived from these catches. The 12 tows made during the second cruise provided insufficient area coverage, thus the results from 73 tows made by the ARCTIC HARVESTER in the same area and during 20 February to 3 March 1981 were used for the analysis. A report by Thompson and McFarlane (1982) details the sampling methods, and results from this cruise.

The fishing positions sampled by the G.B. REED are shown in Fig. 3, while those sampled by the ARCTIC HARVESTER are shown in Fig. 4. The catch information is summarized in Appendix V.

C. HYDROACOUSTIC MEASUREMENT AND ESTIMATION OF FISH BIOMASS

The echo integration system consisted of a Simrad ceramic transducer, a BioSonics precision echo sounder and an Ecosonics digital echo integrator. This system was calibrated against a standard reference hydrophone at the acoustic barge of the University of Washington. Calibrations have been repeated two or three times annually and have shown that the system is stable.

The 38 kHz transducer is mounted in a towed body to reduce roll and pitch as well as ship and flow noise. It is towed from the stern of the vessel by a multiconductor armoured steel cable. The echoes are recorded on a Simrad dry paper chart recorder and the output from the echo integrator is stored on digital cassettes for further processing. Fig. 5 shows a typical echogram. Interpretation of the echogram is simplified by minute marks, depth or range marks, a line that follows the bottom and gives the lower limit of integration, and vertical lines or printout marks that identify the occurrence of an output from the echo integrator. A block diagram of the echointegration

system is shown in Fig. 6, a list of the instruments, their model and serial numbers are given in Appendix I. Appendix II discusses the echo integration equation, systems calibration, and gives a complete list of the instrument settings that were used during the cruises.

The calibrated echo integration system yields an accurate, absolute measurement of the acoustic energy scattered from the insonified fish. An estimate of biomass density is obtained from this measurement if the target strength (TS) of the insonified fish is known. We are unable to measure target strength and therefore have chosen to use values that are published in the literature, a discussion is given in Appendix III. A target strength of -32 dB/kg is used for all air bladder fishes.

Measured target strength values show a slight dependence on fish length and species. This dependence will be ignored as it is small when compared to the scatter that is observed in the TS measurements themselves. Fish behaviour such as tilt angle and depth adaptation can have a strong influence on TS. To minimize these effects we have attempted to survey all areas under similar conditions. Data from day and night surveys and from two major depth layers have been analysed separately.

The TS for dogfish is -47 dB/kg which is only 3% of that for the main species. In the present surveys dogfish account for less than 20% of the total fish biomass, thus, contribute little to the acoustic signal and can be ignored in its analysis. Consequently, the total acoustic biomass estimates are proportioned on the species ratios, dogfish excluded, obtained from the catches. This yields estimates for hake and pollock, while those for dogfish are obtained by extrapolation. In the present situation this approximate method introduces a negligible error (Appendix IV).

RESULTS

A. BIOMASS ESTIMATES BY SPECIES

Each of the three hydroacoustic surveys covered an area of approximately 4500 km^2 and a total transect length of approximately 1000 km (Fig. 1). The following table gives biomass estimates in kilotonnes (kt) for hake, pollock, other fishes with swim bladders and dogfish. The water column is divided into a shallow layer which in most cases extends from 45 to 145 m depth, and a deep layer, below 145 m depth. Fishes within 5 m of the bottom are excluded.

Layer	Survey	Hake	Pollock	Other	Total	Dogfish
Shallow	Jan	13.8	6.3	0.2	20.3	2.1
Shallow	Feb	12.7	5.4	0	18.1	6.4
Shallow	April	(17.8)	(12.8)	-	(30.6)	-
Deep	Jan	35.5	9.4	2.0	46.9	10.0
Deep	Feb	62.4	7.1	0	69.5	8.9
Deep	April	61.7	17.9	1.9	81.5	25.6
Shallow and Deep	Jan	49.3	15.8	2.2	67.3	12.1
	Feb	75.1	12.4	0	87.5	15.3
	April	(79.5)	(30.7)	$\geq$1.9	(112.1)	$\geq$25.6

The estimates for the shallow layer (shown in brackets) in April have been derived using the mean of the January and February ratio of deep to shallow biomass. This approximation was used as the acoustic estimate for the shallow layer was dominated by plankton echoes during April. Brackets are used throughout this report when extrapolated biomass estimates are given. The estimates for hake and pollock are taken from Table 3B and C, those for other species and dogfish from Table 1A, B, and C. The total estimates include all fishes with swim bladder and exclude dogfish.

A further breakdown of the estimates for the subareas is shown in Table 1A, B, and C for the three months respectively. The rows that give the results for the southern and northern half of the Strait of Georgia are labelled by S and N, while those for Sabine Channel, Malaspina Strait and its northern extension are labelled SA, M, and NA respectively. The 'total acoustic estimate' shown includes hake, pollock, and other bladder fishes, the 'total all species' estimate also includes dogfish. Each table gives the estimates for the shallow and deep layer. The species specific estimates are derived from the total acoustic estimate shown in the second column (daytime estimates from Table 2) and the species fractions (Appendix V). The standard error only includes the uncertainty in the species fraction, it does not include errors inherent in the acoustic estimate.

The 'estimate for the total area' represents the sum of the estimates for the subareas and should be close to those in the first row. The '% of totals' gives the fraction of fish found in the shallow and the deep layer as compared to the estimate from 'total depth'.

An overview of the survey results by area and depth has been compiled for the combined estimate of all species (Table 3A) and for hake and pollock (Table 3B and C). These tables summarize the biomass estimates from the three cruises (Table 1A, B, and C) for each area, for the two depth layers and for the total depth. The percentages given in the second and third column show the relative biomass for the upper and lower layer. That given in the fourth column is relative to the cumulative total estimates given in the last row. The last three entries in Table 3B and C give the relative total for hake or pollock, normalized to the total for all species (Table 3A).

During the three surveys approximately 50% of the total biomass was found in the S area, the estimate in this area increased steadily from January through April from 28 to (59) kt. The hake biomass shows a corresponding increase from 22 to (50) kt. The pollock estimate peaks in February with 10 kt.

Approximately 25% of the total biomass was found in the N area, it showed an increase from 19 to (27) kt over the three month period. The data indicate that the hake population dropped from 14 kt to 6 kt, while pollock shows an increase in April after going through a dip in February. The pollock biomass for the deep layer increased from 4 kt to 16 kt. These changes in distribution could be caused by a migration of hake from the N into the S area. Pollock appear to migrate in the opposite direction. The remaining areas accounted for approximately 25% of the biomass, of these the M area is the most important.

On all surveys, approximately 75% of the total estimated biomass was found in the deep layer. A similar depth distribution was apparent in the S and N areas alone. The highest relative hake concentration in the deep layer was found in the S area, it amounted to approximately 92% throughout the survey period. The highest relative pollock concentration was 92%, it occurred in the deep layer of the N area during January.

B. BIOMASS ESTIMATES FOR DAY AND NIGHT SURVEYS

The species-specific biomass estimates shown in the preceeding section are based on the total biomass estimates obtained from the daytime survey data. These and total biomass estimates based on nighttime survey data are summarized in Table 2A and B. By April, it was impossible to cover the area during darkness, thus Table 2C gives daytime estimates only. The tables give the biomass by subareas as well as estimates for the total area. Transect length and area coverage are also shown. In Table 2C, the shallow layer has been split into a 45 to 70 and a 70 to 145 m depth range. This was done in an unsuccessful attempt to exclude the plankton from the fish biomass estimate. Good agreement is obtained between the total day and nighttime biomass estimates. Table 2A and B indicate a difference of 4% and .5% for January and February respectively. Similar agreement is obtained when the results from the shallow and deep layer are compared separately. Individual area estimates show a somewhat larger scattering between day and night but are not dissimilar.

C. ECHOGRAMS AND DEPTH DISTRIBUTION

Echograms were recorded from the 20 log R receiver output and with a chartrecorder gain that was sufficient to display all signals that exceeded the integrator threshold. The depth distribution indicated on the echograms shows a layering throughout the surveys (Fig. 5). When fish were detected in the upper layer above 145 m depth they usually appeared as small, at times

numerous schools in 75 to 125 m. At dusk, these schools break up into a layer of resolved or nearly resolved single fish traces. In the deep layer tight schooling was not observed. Both day and night echograms showed at least partially resolved single fish echoes.

Some of the echograms recorded in April (Fig. 5B) show a plankton layer. This was particularly dense and wide spread in the S and N areas. These layers centered at 120 to 150 m depth. At night, the layers appeared much lighter and at times vanished completely, the plankton presumably rose to the surface.

The plankton layer has a 'grainy' appearance on the echogram. Individual echo returns do not join up to give traces as they are observed for single fish. They are scattered, and a distinct appearance results.

D. BIOMASS DISTRIBUTION

Charts of biomass distributions (Fig. 7 and 8) are presented in terms of surface density expressed in kg/m^2. The biomass surface density for the 'shallow' layer has been plotted for GBR81-1 and -2 (Fig. 7A and B). The heavy plankton layer that was observed during GBR81-4 contributed significantly to the echoes. Therefore, two depth intervals have been plotted for this layer (Fig. 7C and D) in an attempt to separate the plankton from the fish biomass. Surface density charts for the deep layer are shown in Fig. 8A, B, and C. The biomass can be obtained from these charts by multiplying the surface densities by their respective areas. These densities reflect the distribution of the major species: hake and pollock.

E. REPLICATE SURVEYS OF SUBAREAS

In addition to the primary surveys that were carried out in January, February, and April, three opportunities were found to repeatedly survey a small area within a relatively short time. Malaspina Strait, an area off Point Roberts and the Halibut Bank area were chosen. It was felt that these experiments should yield some indication of the reproducibility of acoustic fish density estimates under the present conditions.

1. Malaspina Strait Survey

During the regular survey of Malaspina Strait in January a relatively large biomass was found in this area. This prompted us to make several comparative surveys of the area. Each of these surveys took approximately 4 hr and included transects M02 through M10 (Fig. 1). The total length of these nine transects is approximately 70 km. They cover an area of approximately 164 km^2.

The first and the second survey were run on 20 January 1981 and are part of the regular day and nighttime grid. The third and fourth survey were completed the following night.

Table 4 gives length of transects, area covered and the biomass for each transect as well as the totals. The biomass estimates for the day survey and for the first night survey are 11.2 and 11.5 kt, respectively and are remarkably close, even the agreement between transects is high. This is particularly evident in a plot of biomass versus consecutive transects (Fig. 9 curves D1 and N1). The graph can be viewed as a plot of biomass along the north/south axis of Malaspina Strait.

The two surveys executed during the following night, indicate a sharp decrease in total biomass in the area. The corresponding echograms support this finding. For this night survey Fig. 9 (curve N2) shows a drop of the biomass along transects M3, M4 and M5 to 8.3 kt. The last night survey (curve N3) shows an additional drop along transects M6 and M7 to 6.7 kt.

It is evident that the (estimated) biomass has decreased along the transects, however, it is not clear whether the fish have moved into shallow water, too close to the surface to be 'seen' or whether they have moved entirely out of the survey area. Another possible explanation is that the schools might have moved into the area between transects. It is judged that the observed drop in biomass reflects an actual drop in the quantity of fish in the survey area.

2. Point Roberts Survey

The area considered extends from Point Roberts to the mouth of the Fraser River. It is covered by the eastern portion of the transects S11 through S33 (Fig. 1). This area was first surveyed during the nighttime of January 12 through 15. An additional set of transects S51-S71 (Fig. 2A) was executed during the following two nights. The transects are placed at intermediate positions to the previous set and cover the eastern half of the area. The biomass estimates for both sets of transects and related information are given in Table 5. The total estimates are 8.3 and 9.3 kt, respectively. The standard error on these measurements is approximately ±.3 indicating that the estimates agree at the 95% confidence level. These biomass estimates are plotted versus transect (Fig. 10 upper two curves). The two lower curves give the ratio of the biomass below 120 m depth to that above. This ratio is consistently greater than one, indicating that most of the biomass is found below 120 m.

3. Halibut Bank Survey

An area near Halibut Bank has been surveyed on three consecutive occasions (Fig. 2B). The first survey on 19 April was along the regular set of transects S11 through S17 (Fig. 1). This was followed by two consecutive surveys on the 23 and 24 April. These were carried out along transects R1 through R9 which are 1.5 naut mi apart (Fig. 2B solid lines).

Table 6 gives the biomass for each set of transects. To match area coverage between the S- and the R- series transects, only half the biomass estimates that are given for S11 and S17 in the table are used towards the total area estimate. Good agreement is apparent between the three independent biomass estimates for the 75-520 m depth range. Agreement for the shallow and deep layers is not as good - possibly, indicating a vertical migration. This is not surprising when the survey times are noted (Table 6). An attempt was made to test the significance of these biomass values, however, the integrator printouts were too few and too irregularly spaced. This does not effect the quality of the average data shown, as they are based on a large number of echoes.

DISCUSSION

The interpretation of the results depends on the variance and bias that is expected in the estimates. Standard methods (Shotton 1979) have been used to estimate the sample variance for some of the total biomass estimates given in Table 2. Typical errors in the 15 to 30% range were found. For species-specific biomass estimates the error in the species ratio must be added. In many cases the latter will be negligible for the major species. Bias in the estimates arises from three main sources: System calibration, target strength and differential catching coefficient. Of these system calibration and performance (e.g. stability, time varied gain) will be small. Appendix Fig. III/2 gives an indication of the scatter and possible bias in the TS value. The species specific hydroacoustic estimate does not depend on the absolute amount of fish caught. However it is important that the catching coefficient is the same for all species of interest. One might speculate that the differential catching coefficient is close to one for hake and pollock and that deviations from it are small relative to the potential error in TS. Offshore hake surveys have been reported by Dark et al. (1980). These investigators have used a TS of -35dB, it is based on published values and in situ dual beam TS measurements. The use of -35dB would double all biomass estimates that are presented here. The more conservative value was chosen as it is supported by a large number of recently published TS values. Relative estimates are independent of fish target strength and thus will be more reproducible. If they are based on a measurement of the acoustic backscattering strength of the insonified water column then they will be independent of systems parameters and can be compared between investigations.

Data presented here imply an increase of hake biomass between January and February, however, no change was observed in April. Possible reasons for the increase may be due to one or more phenomena: behavior changes that resulted in a decreased fish target strength, a movement of fish from the surface and bottom towards mid-water increasing their availability for acoustic estimation, or a migration of fish into the survey area. Of these, the last explanation appears most likely. Fish could have entered the survey area from near shore waters and the narrow passages between the islands. Alternately, an influx could have occurred from the inlets (e.g. Jervis and Knight) or the major passages (e.g. Johnstone Strait and Juan de Fuca Strait).

The uncorrected biomass estimate for the shallow layer shows a more than four-fold increase between February and April (Table 2B and C). Examination of a typical echogram (Fig. 5B) and of the echo returns on the oscilloscope indicate that this increase is primarily due to a large plankton biomass that was not observed in the preceeding months. This is supported by the numerous plankton specimen that were entangled in the net. An attempt was made to eliminate this interference by increasing the threshold on the chart recorder and on the echo integrator, however a substantial reduction was not possible without reducing the desired signal from the fish, particularly in the deep layer. Nighttime surveys might have reduced this contribution, however coverage was insufficient for a complete analysis. Reprocessing of the data recorded on analog tape was also considered but was rejected due to the poor results that were obtained. On the other hand an 'order of magnitude' plankton biomass estimate could be obtained if an appropriate TS value were available (Andersen and Zahuranec 1977, Pieper 1979).

The repeated surveys of three small areas indicate that acoustic estimates can be quite reproducible provided that fish do not move out of the survey area. This is particularly true for surveys that are executed during the night when fish are in extended layers rather than schools. The effect of movement is evident in the series of estimates that were made in Malaspina Strait. The trackline spacing was changed between the repeated surveys in the Halibut Bank area. This apparently had little effect on the biomass estimate, indicating that a between transect distance of approximately 3 naut mi is adequate for the present work.

SUMMARY

Three hydroacoustic surveys for hake and pollock were carried out in the Strait of Georgia during January, February, and March 1981. Echo integration was used to determine the total biomass, midwater trawl catches supplied the data for species-specific estimates. The total biomass for the survey area was estimated as 67, 88, and 112 kt during January, February, and April, respectively. These estimates include fish with swim bladders, but exclude dogfish and plankton. Hake was the most abundant species with 73, 86, and 71%, respectively for the three months. Pollock accounted for most of the remaining biomass. The estimate for April is based on incomplete data as plankton interfered with the echo integration estimate. During January and February independent day and night time surveys were conducted. These show close agreement to the subarea level.

Echograms indicate two layers, a shallow one above approximately 145 m depth and a deep layer below. During the day small schools were frequently observed in the shallow layer, which would disperse during the night. The deep layer showed scattered fish distributions. Approximately 75% of the total estimated biomass was found in this layer. Independent day and nighttime surveys show remarkably close agreement and repeated surveys for several subareas show that echo integration can produce a series of consistent biomass estimates under the present condition.

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Table 1. The hydroacoustic biomass estimates are combined with the catch information to yield estimates for each species. The standard deviations are only based on the catch data and do not include the uncertainty in the total hydroacoustic estimate.

Table 1A. GRB81-1 biomass estimates for hake, pollock, and dogfish.

	Biomass (t) 45-145 m depth						Biomass (t) 145-520 m depth					
Area	Total acoustic estimate	Hake	Pollock	Other	Dogfish	Total all species	Total acoustic estimate	Hake	Pollock	Other	Dogfish	Total all Species
All	20335	12974 ±2359	7117 ±2278	244 ±183	1464 ±732	21799	46969	32503 ±5777	13245 ±6294	1221 ±845	7750 ±3288	50257
S	4968	1793 ±1535	2966 ±1545	209 ±114	238 ±144	5206	23098	19795 ±878	1779 ±439	1548 ±808	6722 ±1732	29820[1]
N	4310	3944 ±172	366 ±172	0	534 ±284	4844	14664	10147 ±1804	4135 ±1965	381 ±264	2420 ±1026	15690[1]
NA	2515	1788	727	0	958	3473	1295	896 ±159	365 ±174	34 ±23	214 ±91	1386
M	8272	6096 ±273	2176 ±273	0	356 ±273	8628	6709	3878 ±1087	2811 ±1107	20 ±20	396 ±134	7105
SA	270	172 ±31	95 ±30	3 ±2	19 ±10	289	1203	832 ±148	339 ±161	31 ±22	198 ±84	1287[(1)]
Estimate for total area	20335	13793	6330	212	2105	22440	46969	35548	9429	2014	9950	55288
% of total	30.2	27.9	40.2	9.5	17.5	28.9	69.8	72.1	59.8	90.5	82.5	71.1
Total depth	67304	49341	15759	2226	12055	77728						

(1)Analyzed for 45-120-520-m depth.

Table 1B. GBR81-2, biomass estimates for hake, pollock, and dogfish.

Area	Biomass (t) 45–145 m depth						Biomass (t) 145–520 m depth					
	Total acoustic estimate	Hake	Pollock	Other	Dogfish	Total all species	Total acoustic estimate	Hake	Pollock	Other	Dogfish	Total all Species
All	18100	9991	8109	0	9394[1] 2643	27494 20743	69435	62422	7013	0	8541	77976
S	7220	2960 ±536	4245 ±536	0	5090[2] ±3386	12295	42400	36210 ±1187	6190 ±1187	0	5427 ±848	47827
N	4050	3706 ±486	344 ±486	0	69 ±12	4119	14850	14746 ±45	104 ±45	0	2450 ±1470	17300
NA	2110	1853 ±340	257 ±340	0	464 ±241	2574	775	715 ±49	60 ±49	0	48 ±7	823
M	3460	3038 ±557	422 ±557	0	761 ±394	4221	8960	8270 ±564	690 ±564	0	556 ±81	9516
SA	1260	1153 ±151	107 ±151	0	21 ±4	1281	2500	2483 ±8	18 ±8	0	413 ±248	2914
Estimate for total area	18100	12710	5365	0	6405	24490	69435	62424	7062	0	8894	78380
% of total	20.7	16.9	43.2	-	41.9	23.8	79.3	83.1	56.8	-	58.1	76.2
Total depth	87535	75134	12427	0	15299	102870						

(1) Tow 10 contained a large number of dogfish, if the tow is excluded the estimate for dogfish drops to 2643 t.

(2) Tow 10 contained a large number of dogfish, if it is excluded the estimate for dogfish drops to 1105 ± 267 t.

Table 1C. GBR81-4 biomass estimates for hake, pollock, and dogfish.

Area	Biomass (t) 70-145 m depth						Biomass (t) 145-520 m depth					
	Total acoustic estimate	Hake	Pollock	Other	Dogfish	Total all species	Total acoustic estimate	Hake	Pollock	Other	Dogfish	Total all species
All	74887	52121 ±10934	21942 ±10934	824 ±824	3370 ±1123	78257	81491	75298 ±2282	3504 ±1630	2689 ±1141	13120 ±4889	94611
S	32887	31341 ±1184	789 ±460	756 ±855	1118 ±822	34004	49625	46449 ±1290	1390 ±596	1737 ±794	7047 ±3077	56672
N	24150	8936 ±4685	15190 ±4709	24 ±24	1425 ±411	25575	20770	4839	15931	0	15931	36701
NA	2890	2011 ±422	847 ±422	32 ±32	130 ±43	3020	726	671 ±20	31 ±15	24 ±10	117 ±44	843
M	13400	9326 ±1956	3926 ±1956	147 ±147	603 ±201	14003	7090	6700	390	0	1999	9089
SA	1560	1512	44	5	58	1618	3280	3031 ±92	141 ±66	108 ±46	528 ±197	3808
Estimate for total area	74887	53126	20796	964	3334	78220	81491	61690	17883	1869	25622	107113
% of total	47.9	46.3	53.8	34.0	11.5	42.2	52.1	53.7	46.2	66.0	88.5	57.8
Total depth	156378	114816	38679	2833	28956	185333						

Table 2. Track line length, area coverage, and biomass estimate for the five subareas. The estimates are based on a target strength of -32 dB/kg and include all bladder fishes, primarily hake and pollock, other species may represent 5%. The total estimates are summarized in the last row of the table. Day and nighttime estimates are shown.

Table 2A: Total Biomass GBR81-1

Trackline series	Length[1] (km)	Area[1] (km^2)	Day biomass (t)				Night biomass (t)				
			45-145	145-520	45-520[2]	%	45-145	145-520	45-520[2]	%	
S[3]	477	2,602	4,968	23,098	28,066	41.7	5,790	24,620	30,410	43.4	S. Strait of Georgia
N[3]	290	1,556	4,310	14,664	18,974	28.2	3,749	14,127	17,876	25.5	N. Strait of Georgia
NA	68	117	2,515	1,295	3,810	5.7	2,845	1,760	4,605	6.6	Powell River-Desolation Sd.
M	122	295	8,272	6,709	14,981	22.3	9,425	5,652	15,077	21.5	Malaspina Strait
SA[3]	48	48	270	1,203	1,473	2.2	300	1,761	2,061	2.9	Sabine Channel
Total	1,005	4,618	20,335	46,969	67,304	100	22,109	47,920	70,029	100	

(1) Length and area are for day transects and are similar for night transects.

(2) The depth below the surface meters.

(3) The estimates for this area are based on 45-120-520 m depth ranges.

Table 2B: Total Biomass GBR81-2

Trackline series	Length (km)	Area (km^2)	Day biomass (t)				Night biomass (t)			
			45-145	145-520	45-520	%	45-145	145-520	45-520	%
S	464	2,485	7,220	42,400	49,620	56.7	9,220	43,900	53,120	60.9
N	281	1,439	4,050	14,800	18,850	21.5	3,070	15,900	18,970	21.8
NA	69	141	2,110	775	2,885	3.3	1,620	690	2,310	2.7
M	119	360	3,460	8,960	12,420	14.2	1,400	8,940	10,340	11.9
SA	41	67	1,260	2,500	3,760	4.3	557	1,860	2,417	2.8
Total	974	4,492	18,100	69,435	87,535	100	15,867	71,290	87,157	100

Table 2C: Total Biomass GBR81-4

Trackline series	Length (km)	Area (km^2)	Day biomass (t)					
			45-70	70-145	145-520	45-520	70-520	%
S	473	2,559	2,973	32,887	49,625	85,485	82,512	52.8
N	268	1,374	9,210	24,150	20,770	54,130	44,920	28.7
NA	70	143	400	2,890	726	4,016	3,616	2.3
M	117	356	3,300	13,400	7,090	23,790	20,490	13.1
SA	38	59	300	1,560	3,280	5,140	4,840	3.1
Total	956	4,491	16,183	74,887	81,491	172,561	156,378	100

Table 3. Summary of biomass estimates from the three cruises. The columns for the upper and lower depth give the biomass estimates in t and its relative distribution between the two strata. The percentages given in the last column indicate the fraction of the total biomass that was found in each area.

Table 3A. Total biomass for the combined species excluding dogfish.

Area		All species					
		Upper layer		Lower layer		Total water col.	
S	1	4970	17.7%	23100	82.3%	28100	41.7%
	2	7220	14.6%	42400	85.4%	49600	56.6%
	3	(9590)	(16.2%)	49600	(83.8%)	(59200)	(54.3%)
N	1	4310	22.7%	14700	77.3%	19000	28.2%
	2	4050	21.5%	14800	78.5%	18900	21.6%
	3	(5900)	(22.1%)	20800	(77.9%)	(26700)	(24.5%)
NA	1	2520	66.0%	1300	34.0%	3820	5.7%
	2	2110	73.1%	775	26.9%	2890	3.3%
	3			726			
M	1	8270	55.2%	6710	44.8%	15000	22.3%
	2	3460	27.9%	8960	72.1%	12400	14.2%
	3			7090			
SA	1	270	18.4%	1200	81.6%	1470	2.2%
	2	1260	33.5%	2500	66.5%	3760	4.3%
	3			3280			
Total	1	20300	30.2%	47000	69.8%	67400	100%
	2	18100	20.7%	69400	79.3%	87500	100%
	3	(27700)	(25.4%)	81500	(74.6%)	(109000)	100%

Table 3B. Biomass estimates for Hake.

Area		Hake					
		Upper layer		Lower layer		Total water col.	
S	1	1790	8.3%	19800	91.7%	21600	43.8%
	2	2960	7.6%	36200	92.4%	39200	52.2%
	3	(3980)	(7.9%)	46400	(92.1%)	(50400)	(63.4)%
N	1	3940	28.1%	10100	71.9%	14000	28.4%
	2	3710	20.2%	14700	79.8%	18400	24.5%
	3	(1540)	(24.1%)	4840	(75.9%)	(6380)	(8.0)%
NA	1	1790	66.6%	896	33.4%	2690	5.5%
	2	1850	72.1%	715	27.9%	2570	3.4%
	3			671			
M	1	6100	61.1%	3880	38.9%	9980	20.2%
	2	3040	26.9%	8270	73.1%	11300	15.0%
	3			6700			
SA	1	172	17.1%	832	82.9%	1000	2.0%
	2	1150	31.7%	2480	68.3%	3630	4.8%
	3			3030			
Total	1	13800	28.0%	35500	72.0%	49300	73.1%
	2	12700	16.9%	62400	83.1%	75100	85.7%
	3	(17800)	(22.4%)	61700	(77.6%)	(79500)	(72.9%)

Table 3C. Biomass estimates for Pollock.

Area		Pollock					
		Upper layer		Lower layer		Total water column	
S	1	2970	62.5%	1780	37.5%	4750	30.1%
	2	4250	40.7%	6190	59.3%	10400	83.9%
	3	(1480)	(51.6%)	1390	(48.4%)	(2870)	(9.3)%
N	1	366	8.1%	4140	91.9%	4510	28.5%
	2	344	76.8%	104	23.2%	448	3.6%
	3			15900			
NA	1	727	66.6%	365	33.4%	1090	6.9%
	2	257	81.1%	60	18.9%	317	2.6%
	3			31			
M	1	2180	43.7%	2810	56.3%	4990	31.6%
	2	422	37.9%	690	62.1%	1110	9.0%
	3			390			
SA	1	95	21.9%	339	78.1%	434	2.7%
	2	107	85.6%	18	14.4%	125	1.0%
	3			141			
Total	1	6340	40.2%	9430	59.8%	15800	23.4%
	2	5380	43.2%	7060	56.8%	12400	14.2%
	3	(12800)	(41.7%)	17900	(58.3%)	(30700)	(28.2%)

Table 4. Transect and biomass information for the Malaspina Strait subarea.

Transect	Length (km)	Area (km^2)	Day Jan. 20 Biomass D1 25-125 (m)	Day Jan. 20 Biomass D1 125-500 (m)	Night Jan. 20-21 Biomass N1 25-125 (m)	Night Jan. 20-21 Biomass N1 125-500 (m)	Night Jan. 21-22 Biomass N2 25-125 (m)	Night Jan. 21-22 Biomass N2 125-500 (m)	Night Jan. 21-22 Biomass N3 25-125 (m)	Night Jan. 21-22 Biomass N3 125-500 (m)
M02	5.7	16.1	1550	395	1560	885	1220	301	604	311
			1945		2445		1521		915	
M03	5.8	15.1	758	534	871	354	423	387	512	338
			1292		1225		810		850	
M04	6.9	18.1	1360	425	1360	490	224	419	235	378
			1785		1850		643		613	
M05	6.0	22.2	1010	566	1160	450	443	679	905	293
			1576		1610		1122		1198	
M06	6.1	11.9	462	206	1150	140	1250	156	950	117
			668		1290		1406		1067	
M07	9.8	19.0	1310	1150	1350	172	1330	330	477	239
			2460		1522		1660		716	
M08	9.4	19.1	34*	307*	193*	241*	89.9	151	97.8	170
			341		434		241		268	
M09	11.4	23.2	42*	424	105*	432*	53.8	393	62.5	395
			466		537		447		458	
M10	8.4	18.8	137*	564*	158*	432*	119	364	141	426
			701		590		483		567	
	69.5	163.5	6663	4571	7907	3596	5153	3180	3984	2667
Total biomass (t)			11234 ±744		11503 ±671		8333 ±518		6651 ±298	

*These values are based on 45-120-520 m depth.

Table 5. Transect and biomass information for the Point Roberts subarea.

Row	Length (km)	Area (km^2)	Transect	Date Jan 81	Biomass (t) 45–120 (m)	Biomass (t) 120–520 (m)	Biomass (t) 45–520 (m)	Transect	Date Jan 81	Biomass (t) 45–120 (m)	Biomass (t) 120–520 (m)	Biomass (t) 45–520 (m)
1	13.8	76.7*	S11	12	132*	768*	900*	S71	17	93	214	307
2	14.0	77.9	S13	14	145	233	378	S69	17	123	621	744
3	15.3	85.0	S15	14	163	488	651	S67	17	216	848	1064
4	14.3	79.5	S17	14	323	715	1038	S65	17	361	693	1054
5	13.8	76.4	S19	14	162	626	788	S63	17	304	531	835
6	16.3	98.1	S21	13	192	799	991	S61	17	339	1260	1599
7	11.6	76.0	S23	15	312	826	1138	S59	16	180	600	780
8	9.2	51.4	S25	15	170	215	385	S57	16	253	598	851
9	9.3	42.9	S27	15	159	705	864	S55	16	130	803	933
10	10.9	52.1	S29	15	148	715	803	S53	16	149	432	581
11	10.2	56.7	S31	15	210	395	605	S51	16	127	476	603
12	11.0	61.1*	S33	14	162*	143*	305*					
	137	765			2131	6172	8303 ±277			2275	7076	9351 ±332
Biomass estimate based on rows 1,3,5,7,9,11							8992					8441
Biomass estimate based on rows 2,4,6,8,10,12							7614					10261

*The totals include one-half of these values to account for the slightly larger area covered by S11 through S33.

Table 6. Transect and biomass information from the Halibut Bank subarea.

19.4.81 0715-1355 Biomass (t)				23.4.81 1357-1940 Biomass (t)				24.4.81 0502-1025 Biomass (t)			
Transect	PO #	50-125	125-500	Transect	PO #	50-125	125-500	Transect	PO #	50-125	125-500
S11	25-30	1653	1896								
-				R1	1-6	1442	1363	R1A	45-51	1114	1507
S13	37-43	1842	2347	R3	9-15	3571	1634	R3A	36-42	2943	1600
-				R5	18-27	1508	1854	R5A	24-33	1100	1443
S15	56-65	2315	4341	R7	31-43	1626	1431	R7A	11-21	1084	1528
-				R9	47-52	1133	1358	R9A	2-8	615	2097
S17	70-79	1578	4216								
		5773*	9744*			9280	7640			6856	8175
Total Biomass (t)		15517*				16920				15031	

*1/2 (S11+S17) + S13 + S15.

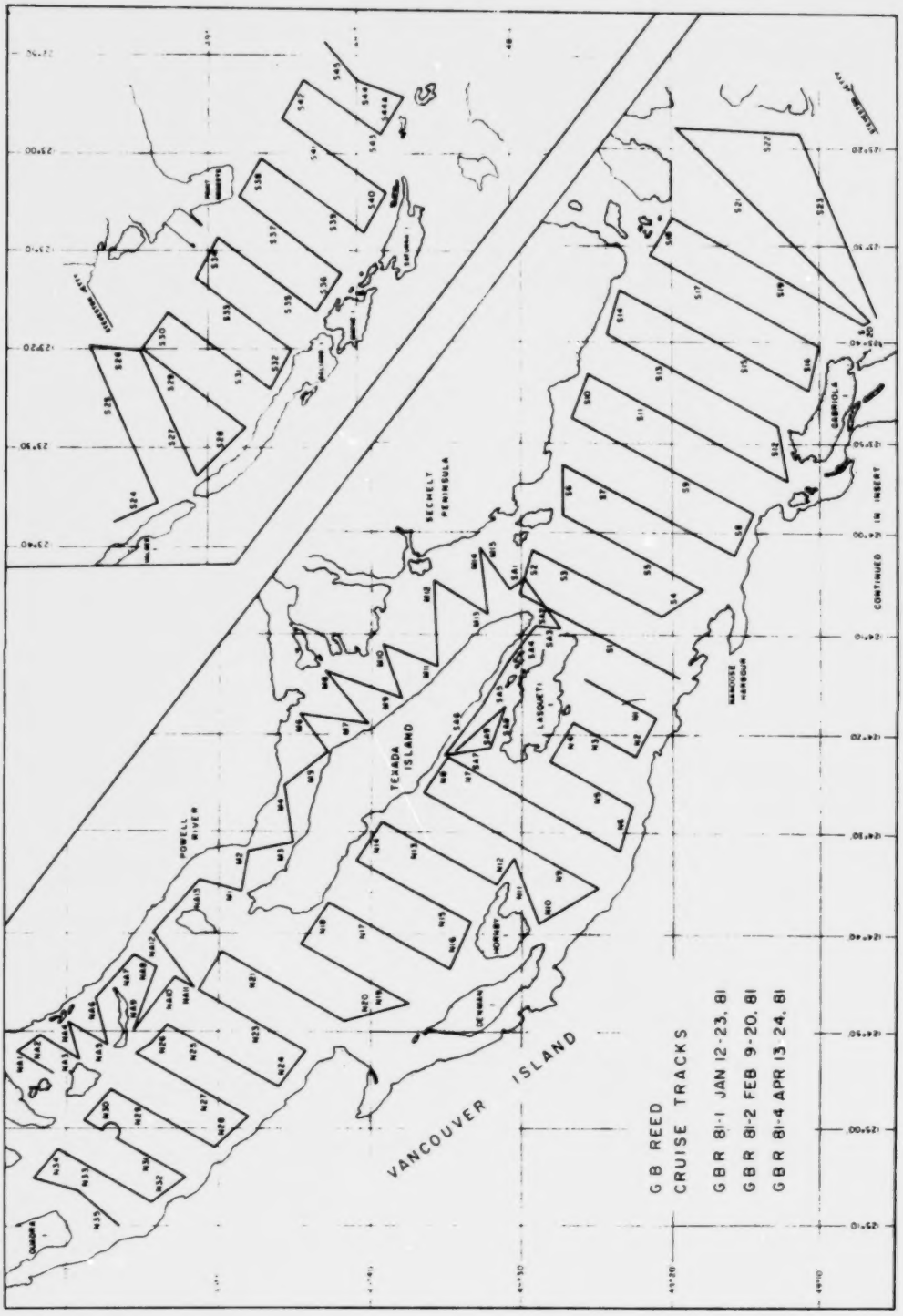


Fig. 1. The survey area and the transects executed during the three cruises.

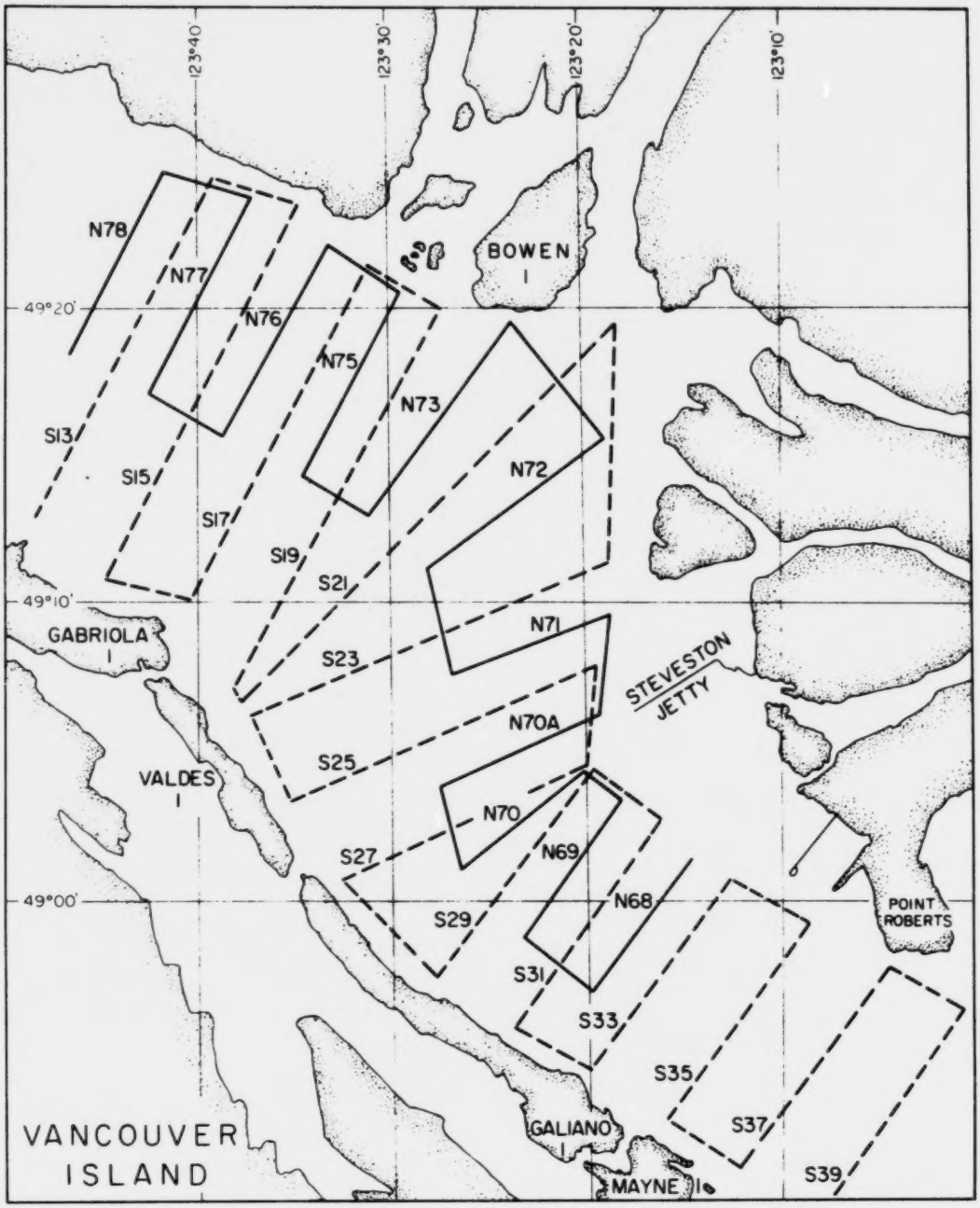


Fig. 2A. Additional tracklines executed during GBR81-1 off Point Roberts.

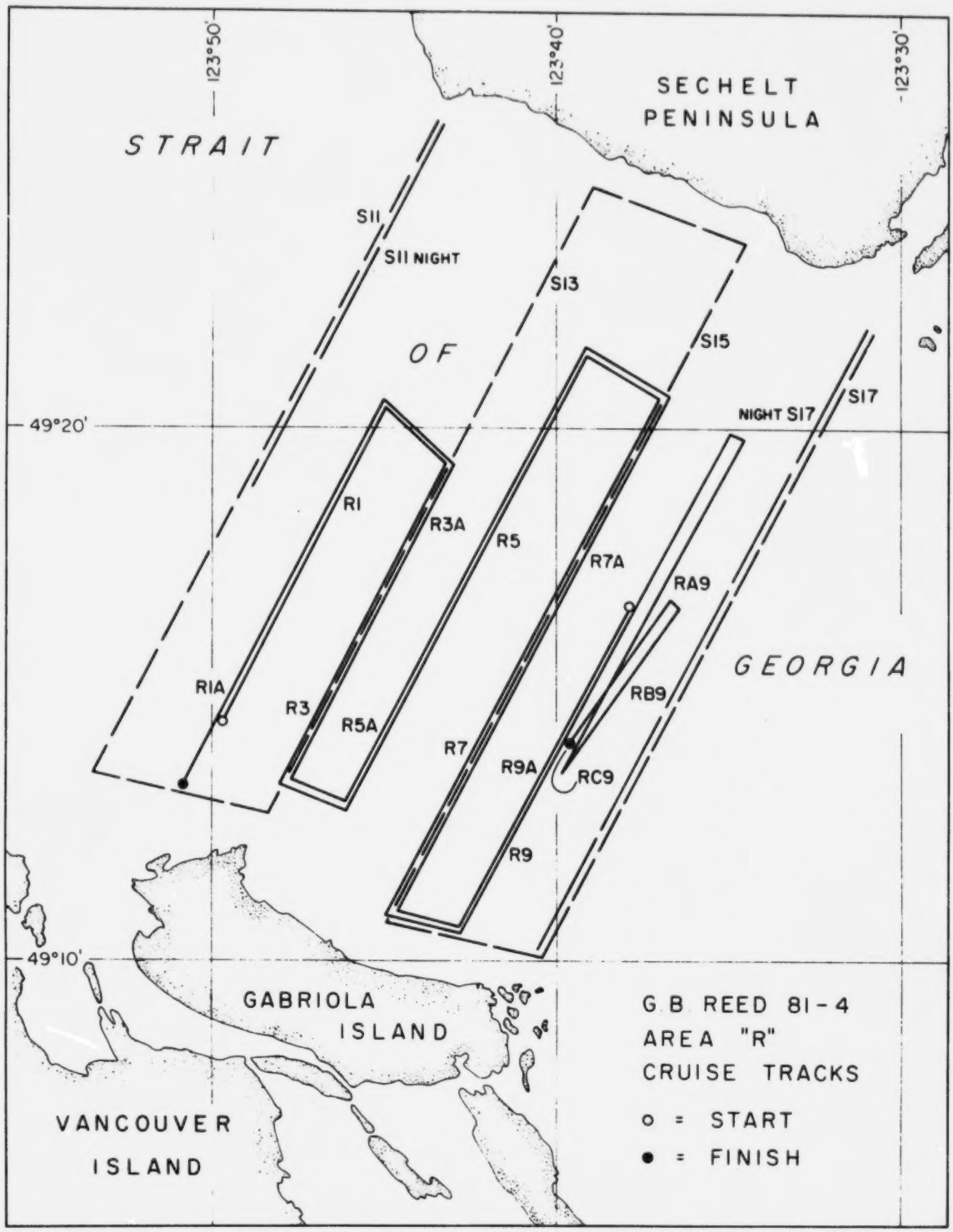


Fig. 2B. Additional tracklines executed during GBR81-4 in the Halibut Bank area.

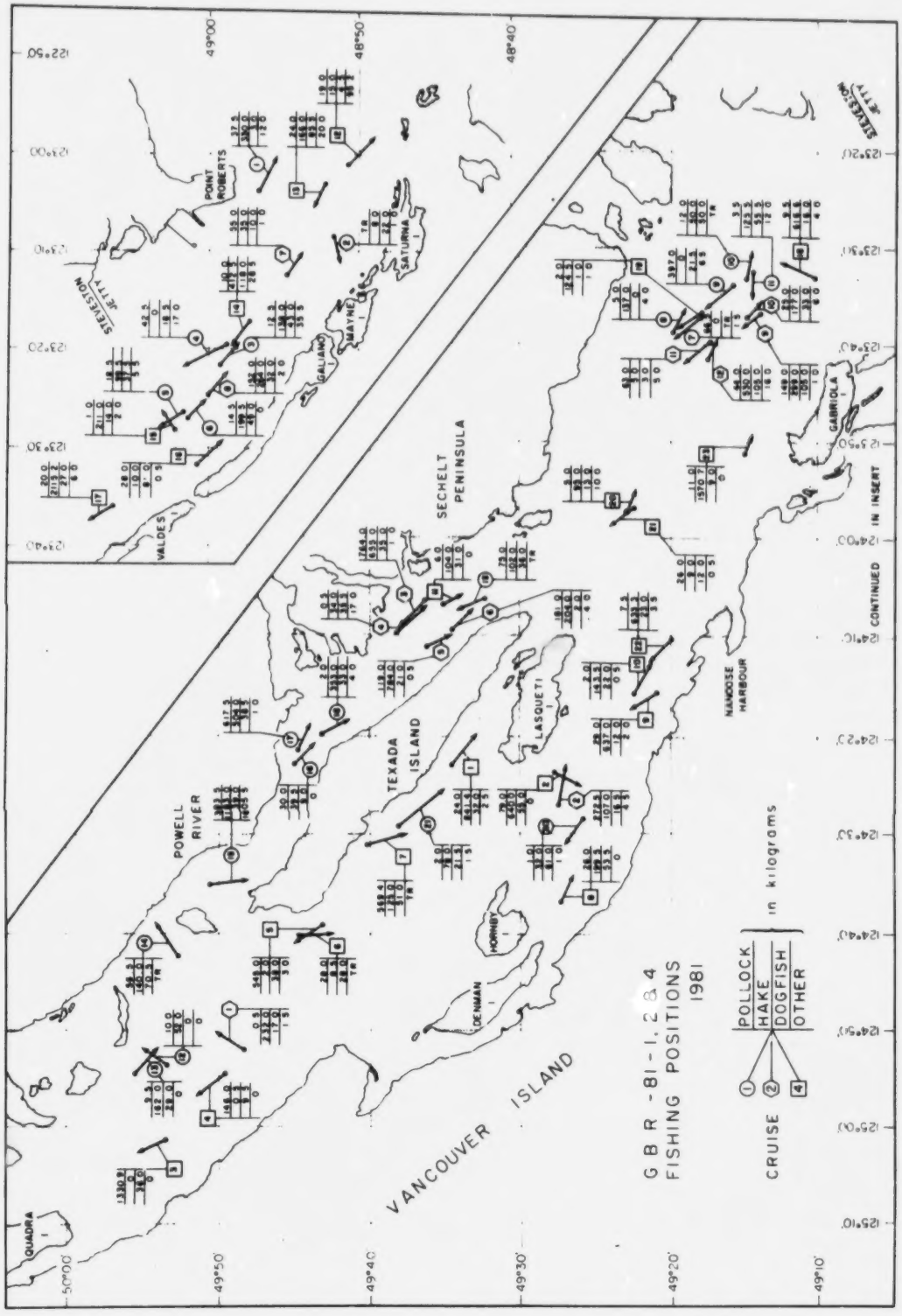


Fig. 3. During the GBR81-1, -2, and -4 cruises, 21, 12, and 23 sets were made respectively. The locations of these sets and the catches are shown for the major species.

Fig. 4. The fishing locations occupied by the ARCTIC HARVESTER, 20 February to 3 March, 1982. The catch compositions from these three sets were used to determine the species composition for the fish distributions encountered during the February cruise (from McFarlane et al. 1982).

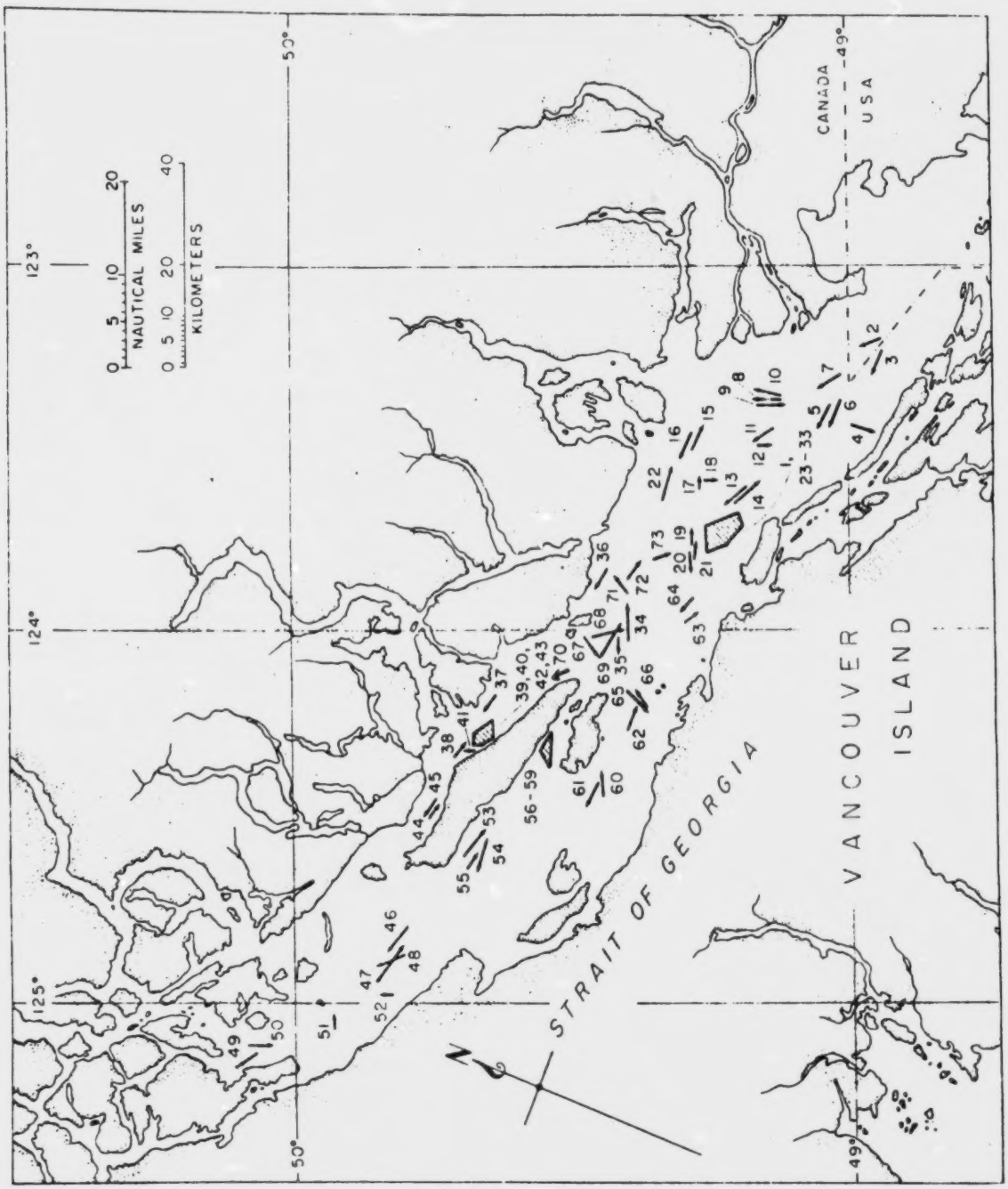

0 5 10 20
NAUTICAL MILES
0 5 10 20 40
KILOMETERS
123°
124°
125°
50°
49°
CANADA
USA
VANCOUVER ISLAND
STRAIT OF GEORGIA
N

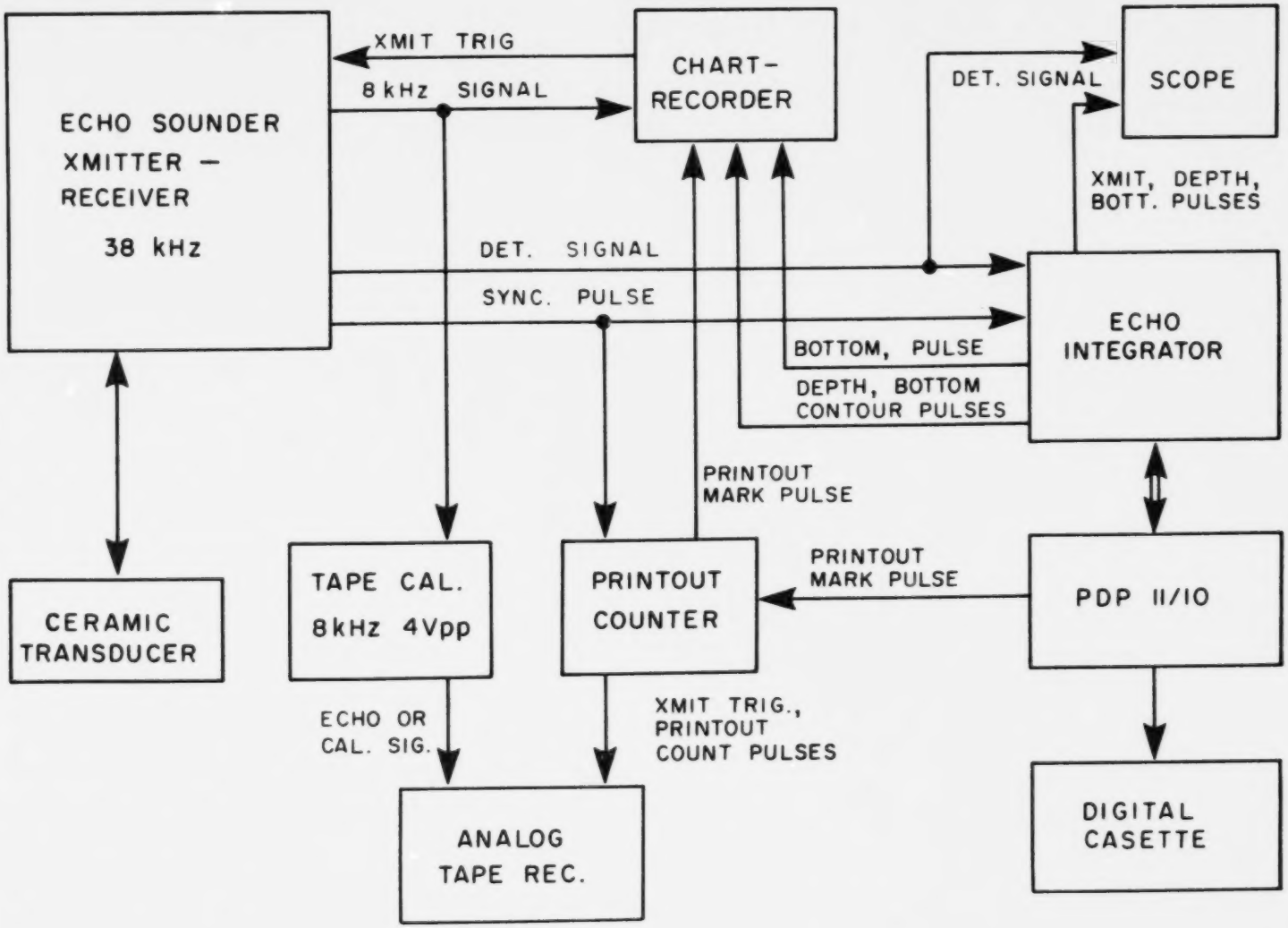
Fig. 5. Typical echograms are shown. The depth or range marks, the bottom tracking line and the printout marks make it easy to correlate echograms and echo integrator output. Minute marks are included for convenience. Both echograms show typical concentrations in the shallow and the deep layer.
A. Recorded during February in Malaspina Strait.

DEPTH
(m)
75
100
125
150
175
200
225
250
END SEA MILE

Fig. 5.
B. Recorded during April in the southern Strait of Georgia, note the heavy plankton layer centered at 150 m depth.

DEPTH
(m)
75
100
125
150
175
200
225
250

Fig. 6. Block diagram of the echo integration system.



ECHO INTEGRATION SYSTEM

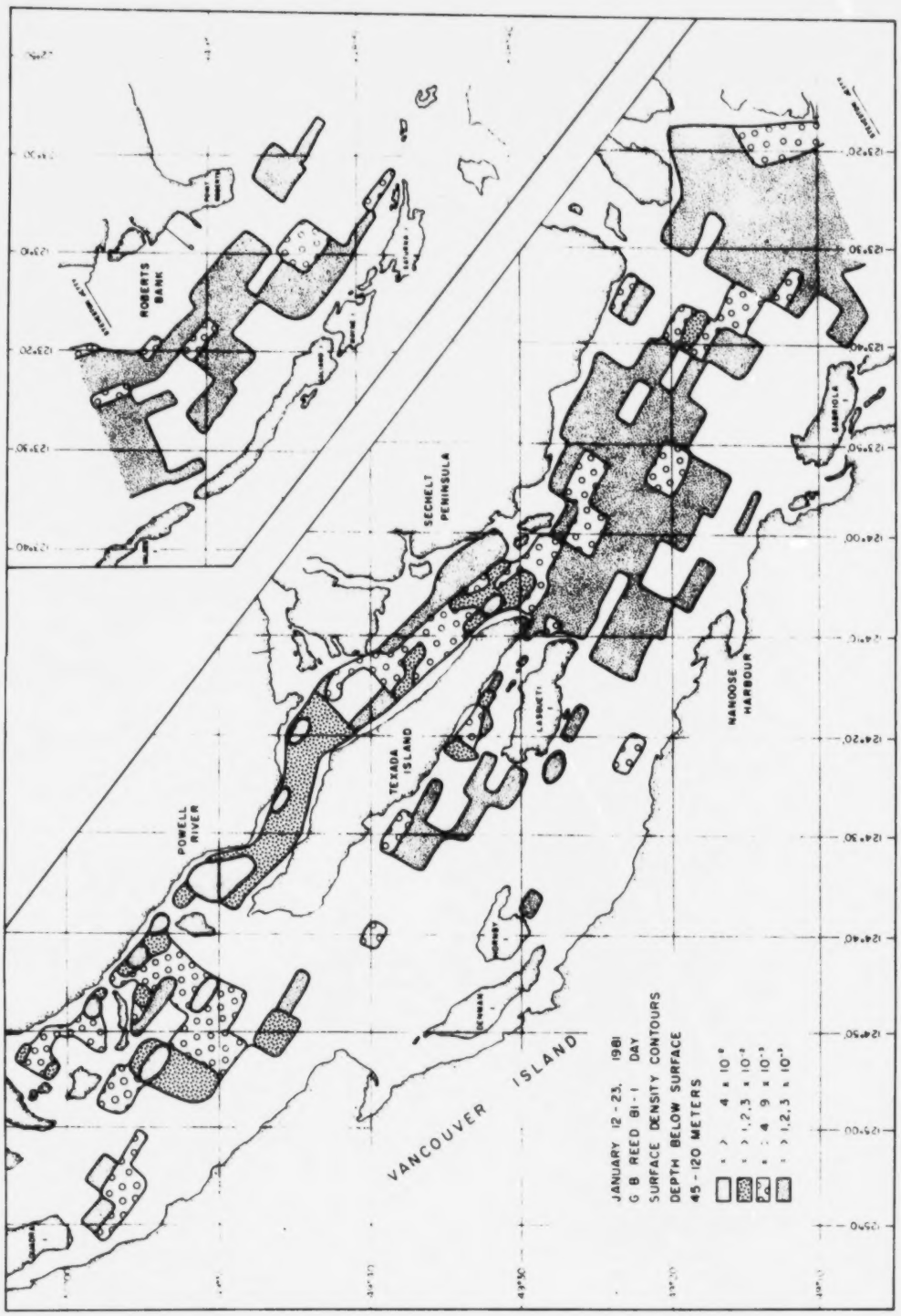


Fig. 7A. Biomass surface density for the upper water column for GBR81-1.

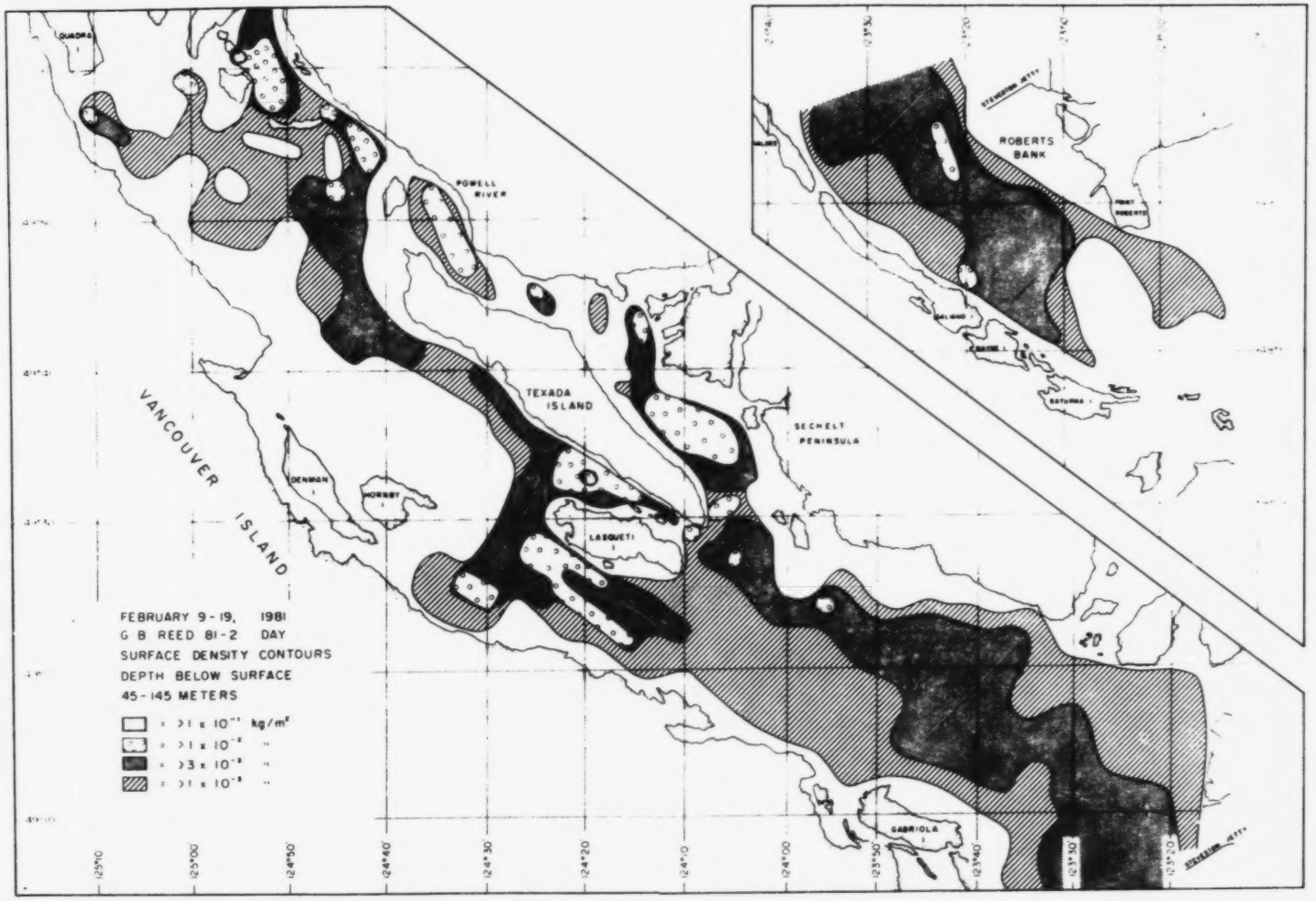


Fig. 7B. Biomass surface density for the upper water column for GBR81-2.

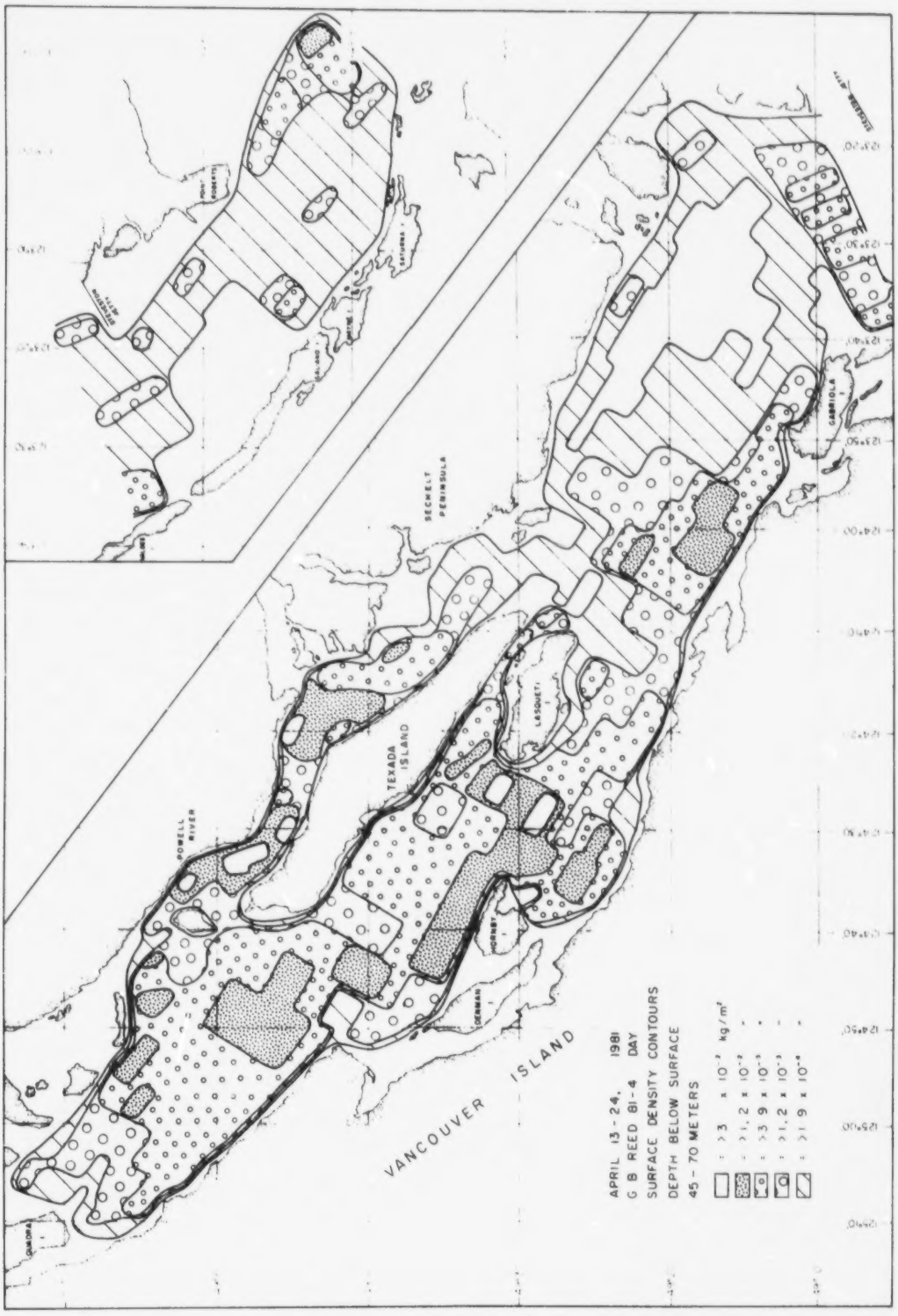


Fig. 7C. Biomass surface density for the upper water column for GBR81-4.

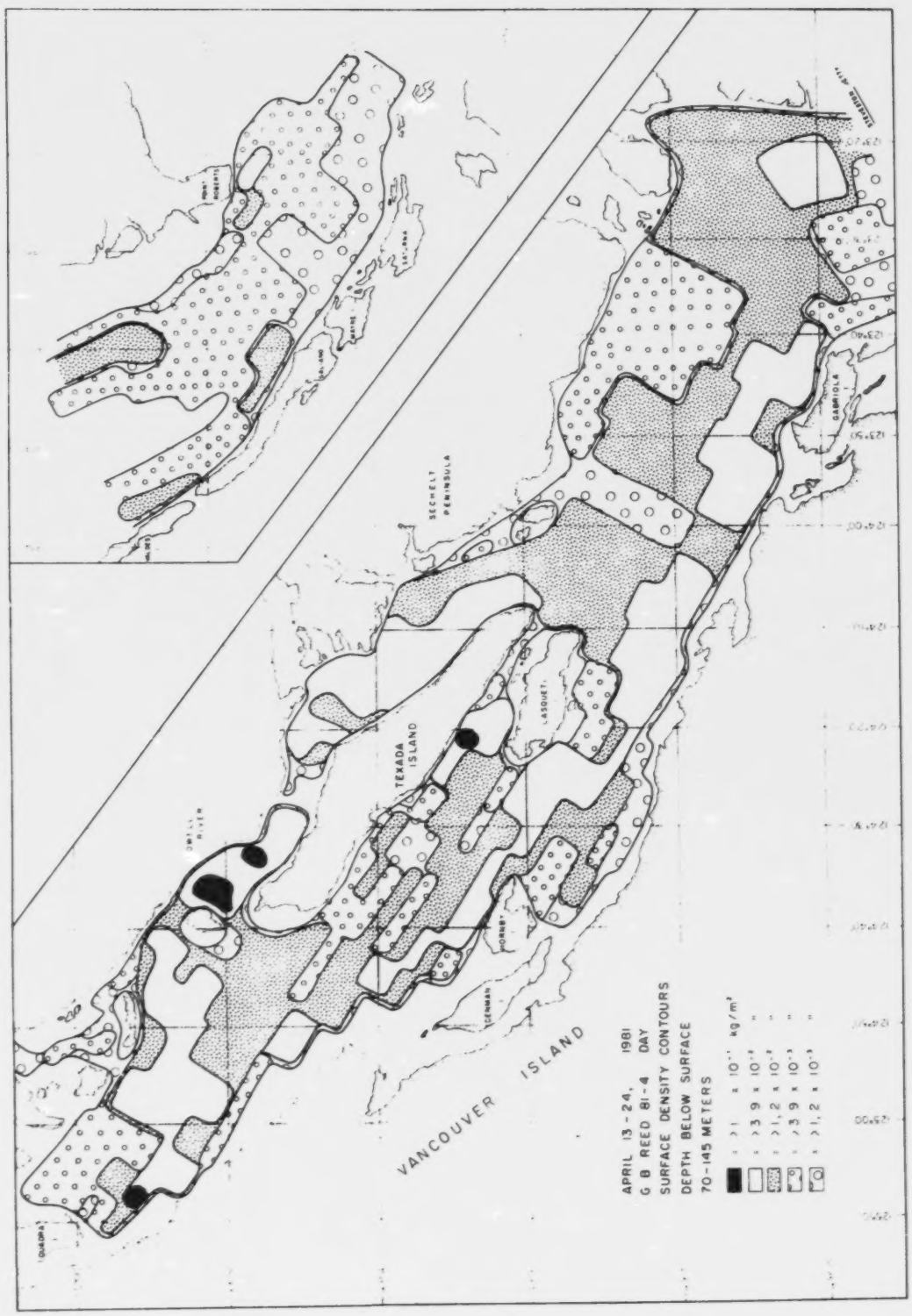


Fig. 7D. Biomass surface density for the upper water column for GBR81-4.

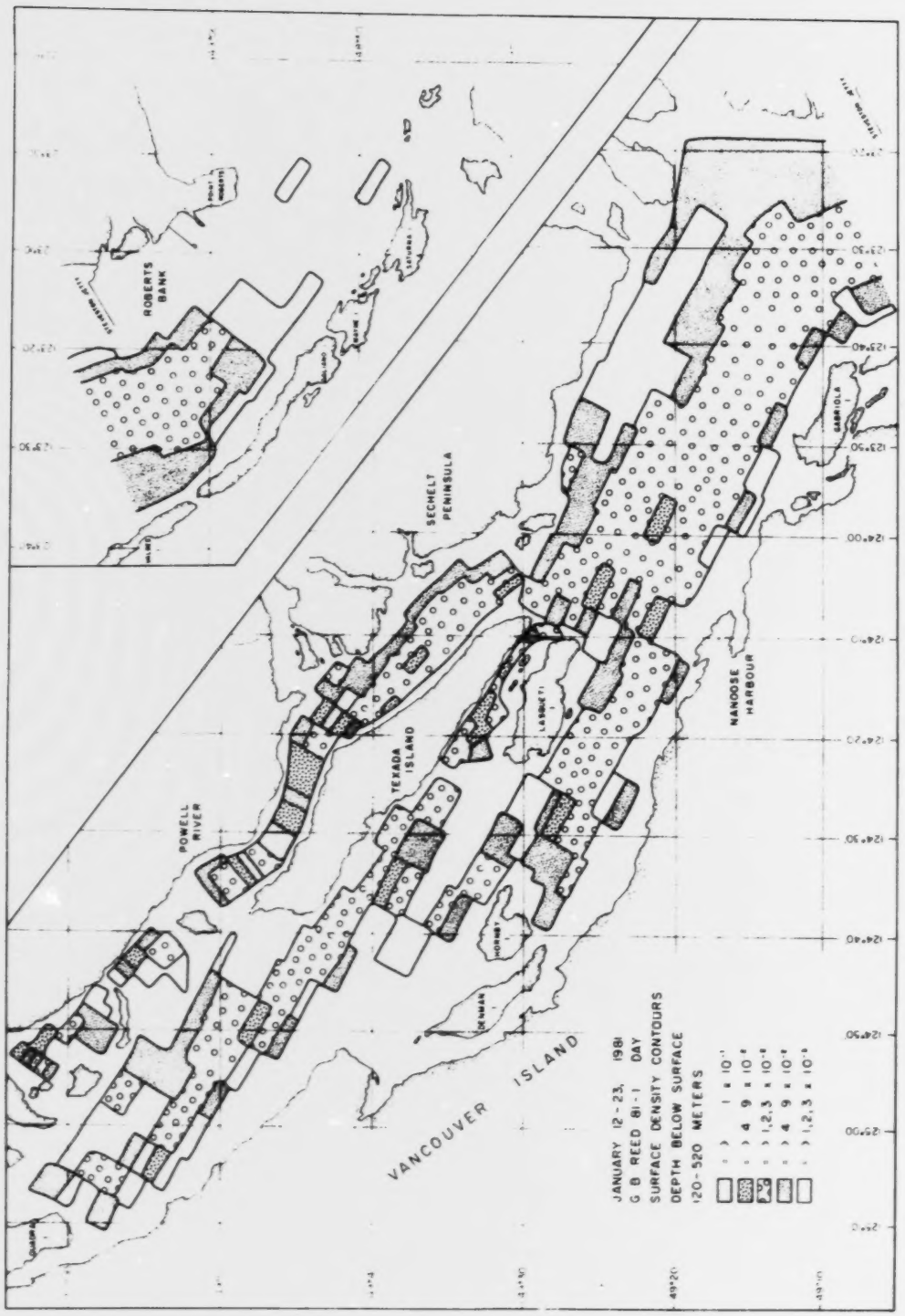


Fig. 8A. Biomass surface density for the lower water column for GBR81-1.

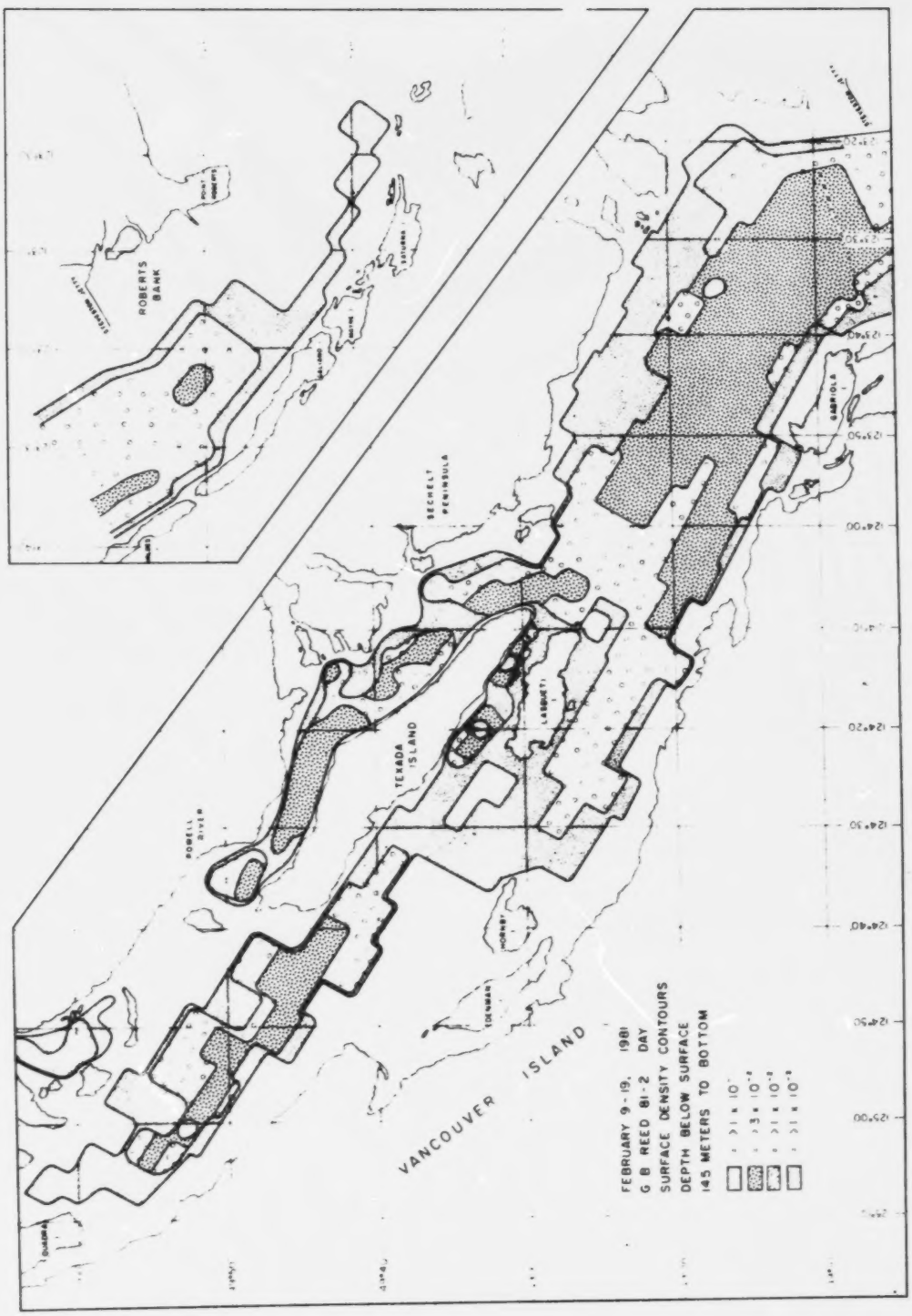


Fig. 8B. Biomass surface density for the lower water column for GBR81-2.

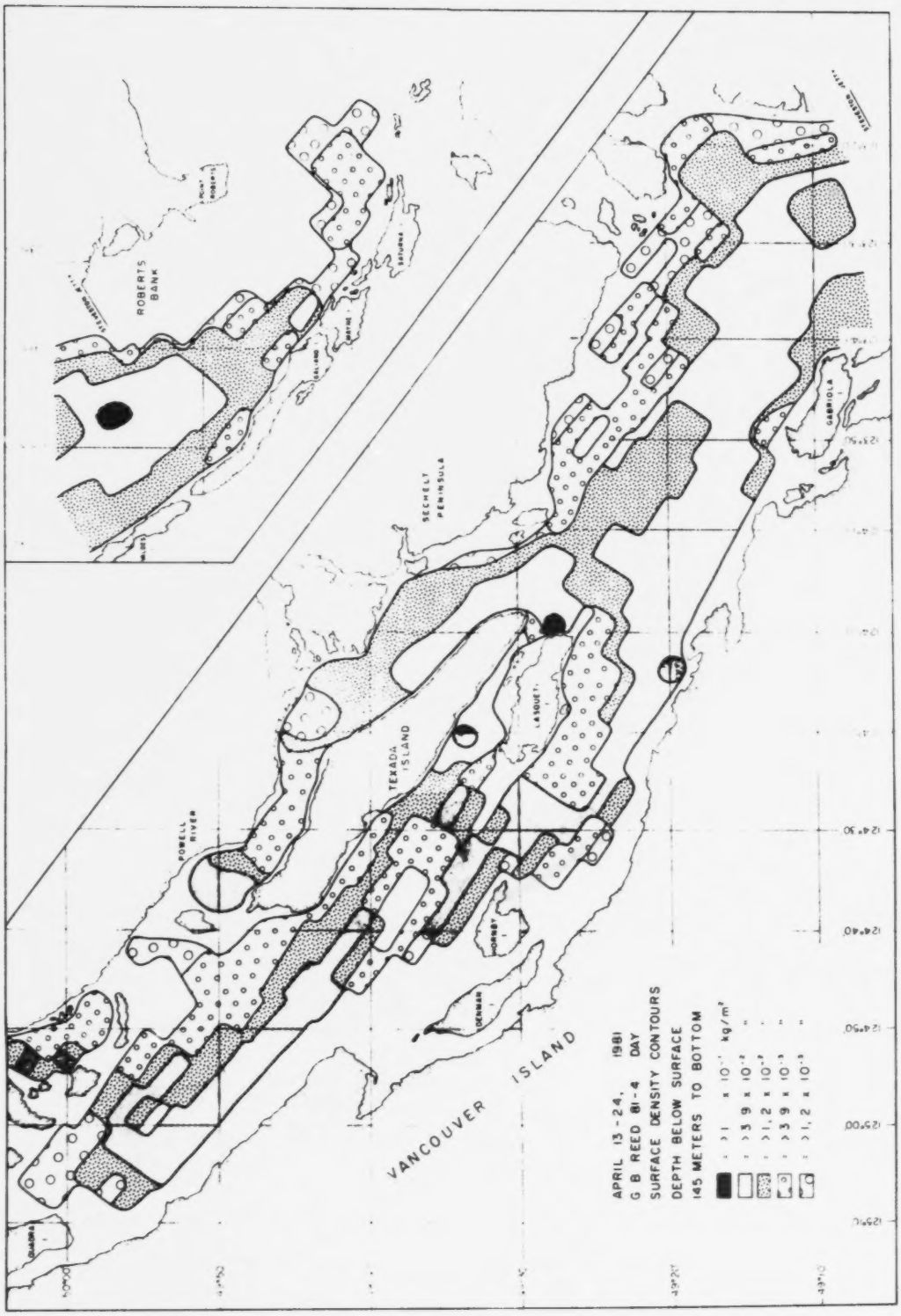


Fig. 8C. Biomass surface density for the lower water column for GBR81-4.

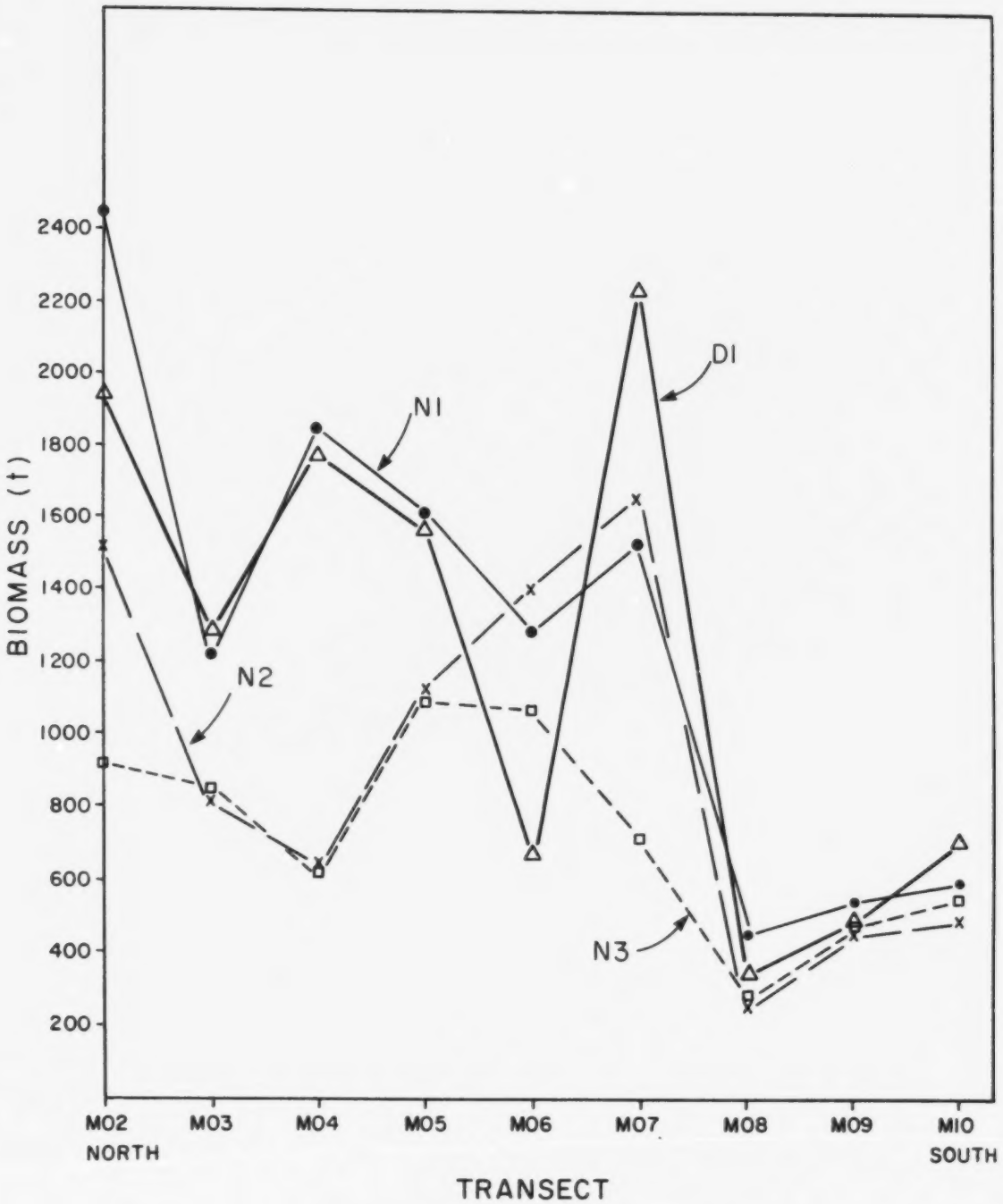


Fig. 9. Biomass versus transect for the Malaspina subarea.

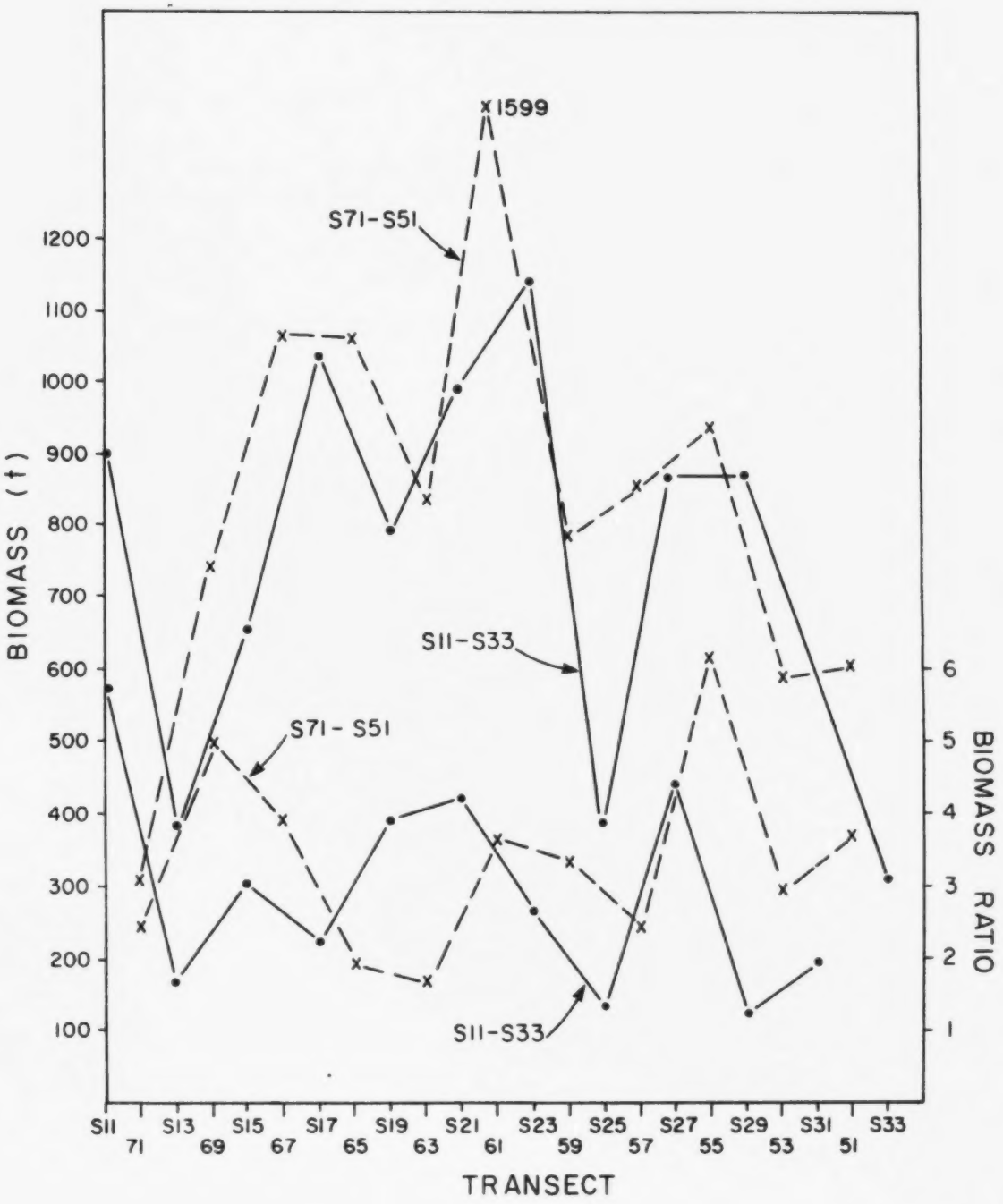


Fig. 10. Biomass versus transect for the Point Roberts subarea. The biomass ratio for the lower and upper layer is shown on the axis at the right.

APPENDIX I

LIST OF HYDROACOUSTIC EQUIPMENT

1. Ceramic transducer: 38 kHz, Simrad model 38-26/22-E 312 038279.6 S4318 15x30 cm active face, 13x7° full beam width between 3 dB points.

2. Towed body: Fathom Oceanology Port Credit, Ontario, Canada. 18 March 1976. Model 3.397-001, Serial 3.347-001.

3. Cable: 100 m long + 30 m extension, three shielded twisted pairs, armoured.

4. Matching: 0.02 µF parallel at transmitter.

5. Echo sounder, transmitter-receiver: Bio Sonics Model 101, Serial 101-79-002.

6. Dry paper recorder: Simrad model 11705, Serial 129.

7. Echo integrator: Echo Sonics.

8. Onboard computer: PDP 11/10 with TU 60 cassette and Silent 700 terminal.

9. Analog tape recorder: Hewlett Packard, Model 3960 F, Serial 1314A01897, Options 050.

10. Oscilloscope: Tektronix 5000, 4-channel storage.

11. Tape calibration, printout marker, in-house design.

APPENDIX II

THE ECHO INTEGRATION EQUATION, SYSTEMS CALIBRATION CONSTANTS, AND INSTRUMENT SETTINGS

A. The Echo Integration Equation and Systems Parameters

The echo integration process can be described by an equation that accounts for the important physical aspects of the measurement, e.g. transmit level and receive sensitivity, spreading and absorption loss, transducer beam pattern, etc. The equation is correct as long as a good signal to noise ratio is available and as long as an average fish target strength can be defined.

For convenience, the parameters are given in logarithmic form throughout this appendix. For each range strata and integration interval the integrator outputs an intensity I that is given by:

$$I = TL + VR + SH + RD + \Omega + CT + BW + RG + TS + RO$$

The following definitions are used:

TL = transmit level, dB re 1μPa at 1 m

VR = voltage response, dB re 1V/μPa at 100 m TVG

SH = transmit and receive loss through the shell of the towed body

RD = spreading and absorption loss at reference distance = $20\log R + 2\alpha R$

Ω = beam factor = $10 \log \left[\iint_{4\pi} b^2 (\theta,\phi) \sin\theta \, d\theta \, d\phi\right]$

$b(\theta,\phi)$ = one way transducer directivity function

CT = range increment = $10 \log c\tau/2$
c = velocity of sound in water,
τ = transmit pulse width

BW = band width factor = $10 \log I_1/I_0$
I_1 = integrator output from a band width limited receiver
I_0 = integrator output when a square wave signal input of the same pulse height as I_1 is used

RG = receiver gain setting

TS = average fish target strength

RO = fish volume density

These parameters have been carefully determined and are given in Appendix Table II/1. The first three values have been measured at the hydroacoustic calibration facility of the Applied Physics Laboratory of the University of Washington in Seattle (calibration date 6 January 1981). This calibration is performed periodically and provides a check on the overall system performance and stability.

Appendix Table II/1. The quantities used in the echo integration equation are given. The values for TL, VR, SH, and Ω are based on a hydroacoustic calibration that is repeated regularly.

Quantity	Value (dB)	Comment
TL	223.3	Measured at hydroacoustic barge, APL University of Washington 6 January 1981.
VR	-98.8	
SH	-1.0	
RD	-41.98	R = 100 m, α = .0099 dB/m
Ω	-17.55	
CT	-3.47	c = 1500 $\frac{m}{s}$, τ = .6 ms
BW	-.96	
RG	-12.0	
TS	-32.0	See Appendix III
RO	???	Parameter to be estimated

With these parameters the echo integration equation is

$$I = K + TS + RO$$

where K = overall gain constant = 47.54 dB

The hydroacoustic calibration determines TL and VR with an approximate accuracy of ±.5 dB. Relative calibration measurements approach ±.1 dB. Thus the accuracy and precision of K are estimated as ±1 dB and ±.2 dB, respectively.

B. Instrument Settings used Throughout the Surveys

The following list of instrument settings is given for reference purposes, it also indicates some important operational characteristics that will be highlighted below. The following settings were used for all three cruises:

Bio Sonics Echo Sounder:

Receiver gain -12 dB
Band width 5 kHz
Attenuation -9.9 dB/km
TVG 20 log R
Cal. off
Calibration pulse separation 3 m
TVG range 5-500 m
Blank at range
Ping repetition 1.2 sec
Ext. trigger
Pulse width .6 m/sec
Transmit power 1000 W
Low pass filter preceeding the detected output 2 kHz

On board computer:

PDP 11/10
Operating system: DEC CAPS 11
Integration software: INT2

Echo Sonics Integrator:

Xmit trigger threshold 2 V
Bottom trigger threshold 2 V (via 300 Hz RC filter)
External trigger
Gain OdB (not used)
Printout after 333 pings
Normalization constant 1
Threshold .1V or .2V depending on background signal level (see text)
Bottom buffer 5 m
Range strata m:

5	50	175	300
10	75	200	350
15	100	225	400
20	125	250	450
25	150	275	500

HP Analog tape recorder:

3 3/4 in/sec speed
Signal chan II
Trig chan IV
Chan I, III record amplifier off
Tape calibration II 8 kHz, 4 Vpp + 100%
Tape calibration IV 8 kHz, 4 Vpp + 50%

Chart recorder:

Gain 30 or 24 dB for .1 or .2 V integration threshold respectively (see text)
Subbottom gain 100
White - and contour line on
C scale, ping repetition 1.2 sec
Write intensity 2
Threshold off
Paper speed fast

The receiver gain and integrator threshold were chosen to accommodate both single fish and fish schools. Observation of the detected output on the oscilloscope indicated that heavy schools seldom exceeded the 5 V level while single fish, presumably hake or pollock of approximately 40 cm length would show as echoes of 0.2 V and larger. A detection threshold (integrator threshold) of 0.1 V was chosen whenever possible. The threshold had to be raised to 0.2 V during the third cruise to at least partially discriminate against the heavy plankton layers present during April.

The detected output from the receiver is linear to 10 V, while the echo integrator accepts a maximum input level of 5 V only, thus echoes that exceed 5 V will be clipped. The chart recorder gain is set so that any signal above the integrator threshold voltage is just sufficient to produce a light trace. In this way the echogram provides an optimum impression of the signals actually integrated. It is important to look at the smaller signals above the threshold as they are much more frequent than large fish signals and thus can contribute a major portion to the integrated output.

APPENDIX III

TARGET STRENGTH

Several investigators have measured and published fish target strength (TS) values. In general it depends strongly on parameters such as fish species, size, depth adaptation, presence or absence of a swim bladder, attitude, swimming behaviour, maturity, and others. Even for a given fish species and size individual TS measurements fluctuate widely, however considerable evidence exists that stable average TS values can be obtained under a wide range of conditions.

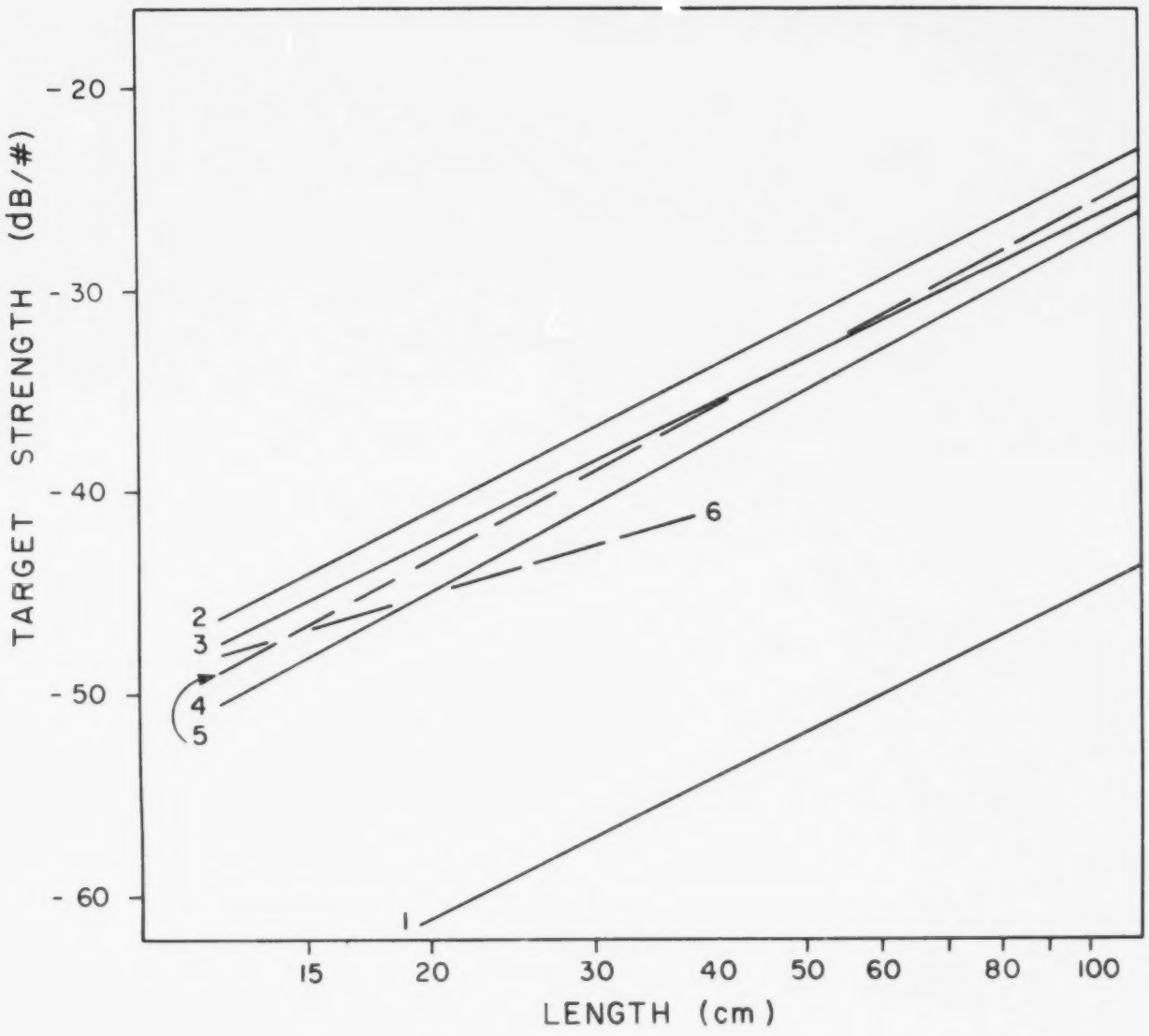
At the time when this cruise was planned, executed and analysed, target strength generally had been measured per fish, rather than per kg. For the present purpose the latter values are more desirable as they are less dependent on fish length. This Appendix gives the information that lead to the particular choise of TS.

A. Average Target Strength for Individual Fish

Target strength values for individual fishes (TS/#) have been measured in several laboratories. Earlier measurements usually have been made of the maximum dorsal TS. These are generally higher than the "expected field values" which are quoted from the literature. Appendix Table III/1 gives equations for the TS/# at 38 kHz as a function of fish length. Sample values for 20, 50 and 100 cm fish length are shown along with species names and literature references.

Appendix Table III/1. The TS/# values given are "expected field values", the values for dogfish may be a maximum dorsal target strength. All lengths are in centimeters.

	TS/#	TS/# dB for L cm			Species	Reference
		20	50	100		
1	22.5 log L -89.9	-60.6	-51.7	-44.9	Dogfish	Goddard 1975
2	23.5 log L -71.5	-40.9	-31.6	-24.5	Cod	Forbes 1975
3	22.7 log L -72.0	-42.5	-33.4	-26.6	Haddock	Forbes 1975
4	25.6 log L -78.3	-45.0	-34.8	-27.1	Saithe	Forbes 1975
5	24.6 log L -75.1	-43.1	-33.3	-25.9	Cod	Nakken 1977
6	13.6 log L -62.8	-45.1	-39.7	-35.6	Herring	Nakken 1977



Appendix Fig. III/1. Average target strength values for individual fishes are plotted against fish length. The numbers on the lines refer to the row numbers in Appendix Table III/1.

Appendix Fig. III/1 shows a plot of TS/# versus fish length. The numbers on the curves refer to the row numbers in Appendix Table III/1. The lines fall into two categories: one for dogfish, the other for bladder fishes. The strong dependence of TS/# on fish length is apparent. Consequently fish length has to be known before the fish number density (#/m^3) can be estimated from the echo integrator output. This problem is much reduced when the biomass rather than the number of fish is to be estimated.

B. Average Target Strength for Fish Biomass

Alternately target strengths can be referred to unit mass of fish rather than to individual fish. These values are known as target strength per kilogram (TS/kg).

Appendix Table III/2. Length-weight relationships for Pacific herring, pollock, and dogfish. Weight is in grams; length is in centimeters.

Weight	Species	Reference
$W = 0.005114\ L^{3.321}$	Herring	Larkin 1965
$W = 0.00597\ L^{3.056}$	Pollock	Thompson pers. comm.
$W_m = 0.00233\ L^{3.09}$	Dogfish male	Jones 1977
$W_f = 0.00327\ L^{3.03}$	Dogfish female	Jones 1977

Appendix Table III/2 gives length-weight relationships for herring, pollock, and dogfish. The length weight relationships can be combined with the TS/# values given in Appendix Table III/1 to give an estimate of TS/kg.

$$TS/kg = TS/\# + 10 \log \frac{1000}{W}$$

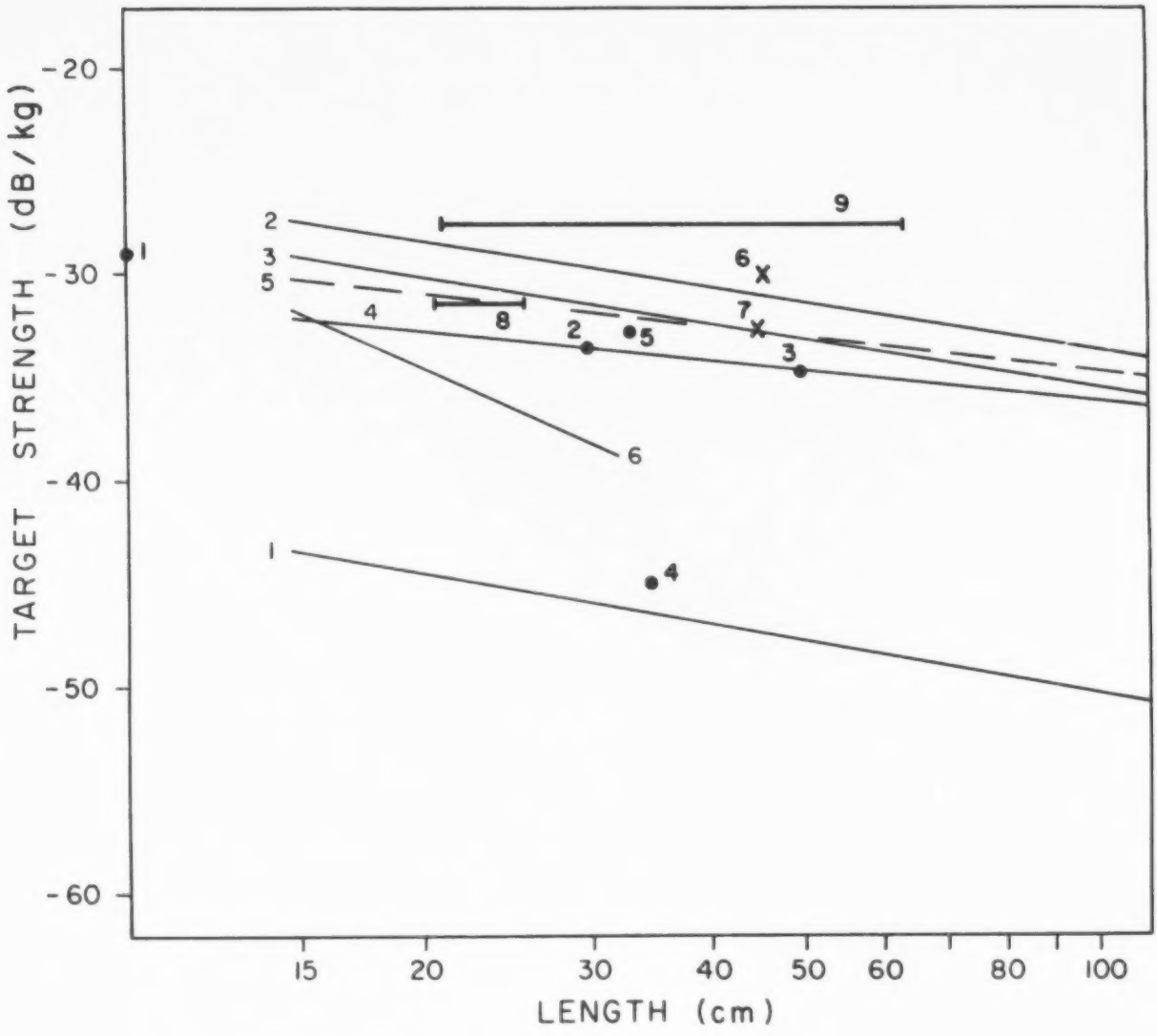
Where 1000/W gives the number of fish per 1000 g. The resulting target strength equations and typical values are given in Appendix Table III/3.

Appendix Table III/3. The TS/kg equations have been obtained from the TS/# equations and from the length weight relationships shown in the first two tables.

	TS/kg	TS/kg dB for L cm			
		20	50	100	Species
1	- 8.4 log L -33.6[1]	-44.5	-47.9	-50.4	Dogfish
2	- 7.1 log L -19.3[2]	-28.5	-31.4	-33.5	Cod
3	- 7.9 log L -19.8[2]	-30.1	-33.2	-35.6	Haddock
4	- 5.0 log L -26.1[2]	-32.6	-34.6	-36.1	Saithe
5	- 6.0 log L -22.9[2]	-30.7	-33.1	-34.9	Cod
6	-19.6 log L - 9.9	-35.4	-43.2	-49.1	Herring

(1)The length-weight equation for male dogfish has been used.
(2)The pollock length-weight relationship has been used.

These equations are shown in Appendix Fig. III/2. It is evident that the TS/kg values show a much smaller length dependence. This figure also shows the TS/kg values that are compiled in Appendix Table III/4. Most of these are quite recent and represent direct measurements of TS/kg rather than TS/# measurements that have been converted. The spread of measurements shown in Appendix Fig. III/2 indicates that the TS/kg value may introduce a bias of several dB.



Appendix Fig. III/2. Average target strength values per kg of fish are plotted against fish length. The numbers on the lines refer to the row numbers in Appendix Table III/4.

Appendix Table III/4. Published TS/kg values. The values in row 5 through 9 are based on direct measurements. Those in row 1 through 4 have been derived from TS/# values. The last values for herring and cod were not available at the time of the present surveys and were not considered in deriving the TS/kg of -32 dB which is used throughout this report.

	Species	Length (cm)	TS/kg	Method	Reference
1	Cod, saithe, herring	10	-29.0	Caged fish	ACMRR 1978
2	Cod, saithe, herring	30	-33.5	Caged fish	ACMRR 1978
3	Cod, saithe, herring	50	-34.5	Caged fish	ACMRR 1978
4	Makerel	35	-45.0	Caged fish	ACMRR 1978
5	Walleye pollock	33.6	-32.8	In situ, dual beam measurement	Traynor 1979
6	Walleye pollock	47	-29.9	Day, dual beam measurement	Traynor pers. comm.
7	Walleye pollock	47	-32.7	Night, dual beam measurement	Traynor pers. comm.
8	Herring	21-25	-31.5	Caged fish	Edwards 1980
9	Cod	22-64	-27.7	Caged fish	Forbes 1980

Observed average lengths for hake, pollock, and dogfish are shown in Appendix Table V/3. The samples were taken during the first cruise and are representative for all three cruises. The average lengths for hake are between 35 and 49 cm. Those for the other two species are similar. The length dependance of the TS/kg values shown in Appendix Fig. III/2 is negligible over this range, consequently a TS of -32.0 dB/kg has been selected for all fishes with swim bladders and -47.0 dB/kg is used for dogfish.

APPENDIX IV

AN APPROXIMATE METHOD FOR OBTAINING SPECIES SPECIFIC BIOMASS

The echo intensity I can be regarded as the sum of the intensities I_i that are received from the different fish species or size groups of target strength t_i.

$$I = \sum_i I_i = K \sum_i \rho_i t_i \qquad \text{IV/1}$$

where: K = overall systems gain
ρ_i = volume density of species i (kg/m^3)
t_i = target strength for species i.

Alternately, I can be expressed in terms of the total biomass density ρ:

$$I = K\rho t$$

where: $\rho = \sum_{i=1}^{n} \rho_i$ = total biomass density

$$t = \frac{\Sigma_i \rho_i t_i}{\Sigma_i \rho_i}$$ = average target strength

Absolute biomass density estimates ρ_i can be obtained with additional information on the species ratio. The relative catch is used to obtain the relative density:

$$\frac{m_i}{m} = \frac{\rho_i}{\rho}$$

where: m_i = catch of i^{th} species
$m = \Sigma_i m_i$ = total catch

thus: $t = \frac{1}{m} \Sigma_i m_i t_i$.

In the present situation, two acoustically different groups of fish are to be analysed: fishes with swim bladders and dogfish. Of these, dogfish has a much smaller TS (-47 instead of -32 dB) and represents a small fraction of the catch. Consequently, it contributes little to the average TS and can be ignored in the analysis of the echo intensity. Thus, the total acoustic biomass estimate is simply partitioned in accordance with the catch ratios excluding dogfish. The dogfish biomass is obtained by extrapolation. The following example demonstrates the small error that is introduced by this approximate calculation. A species mixture of 80% hake and 20% dogfish is assumed.

Exact method	Approximate method	Difference
$I = K \rho (.8x10^{-32/10} + .2x10^{-47/10})$	$I = K \rho' 10^{-32/10}$	
$\rho = \frac{I}{K}$ 1966	$\rho' = \frac{I}{K}$ 1585	
ρ hake $= .8 \rho \propto 1573$	ρ' hake $= 1.0 \rho' \propto 1585$	+.8%
ρ dogfish $= .2 \rho \propto 393$	ρ' dogfish $= .25 \rho' \propto 396$	+.8%

The difference between the estimate from the 'exact method' and the 'approximate method' is small, however, it is important to relize that the uncertainty in the biomass estimate will increase with decreasing TS and decreasing relative biomass.

APPENDIX V

MIDWATER TRAVEL CATCHES AND SPECIES RATIOS

Appendix Table V/1 give the catches for hake, pollock, dogfish and "others" as well as basic tow information, such as tow number, location, date, time, duration of set and head line depth. The three identified species account for approximately 98% of the total catch. The tow locations are shown in Fig. 3 and 4.

Appendix Table V/2 gives the 'species fraction'. It is the ratio between the total catch of a particular species and the sum of the catches of all species except dogfish. The species fraction can be used directly to scale the total hydroacoustic biomass estimate for the area of interest.

The first colunm in Appendix Table V/2 lists the tows that were used for the analysis of each area. In some cases, only one tow was available. Some areas have no catch information, in these cases all tows from the top or bottom layer were used.

The standard error given with most species fractions only includes the sample variance of the catch data. In many cases the indicated uncertainty is relatively large especially if a species other than the most abundant one is considered.

No attempt has been made to reduce the variance by adopting a stratified sampling design. Such an approach might be possible in some subareas where a relatively large number of tows are available.

Appendix Table V/3 gives the fork length and standard deviations for the major species that were sampled during GBR 81-1. This information is important for the determination of the target strength value.

Appendix Table V/1A. Tow and catch information for the January survey. The sets were made by the G.B. REED. Head line depth is given, the vertical net opening was approximately 11 m.

Tow no.	Lat.	Long.	Date	Time Start:Run	Depth	Catch total	Hake Wt (kg)	Hake %	Pollock Wt (kg)	Pollock %	Dogfish Wt (kg)	Dogfish %	Other Wt (kg)	Other %	Transect	
1	48:56.5	123:03.8	15-Jan-81	1352:40	103	383.0	330.0	(86.2)	38.0	(9.9)	3.0	(0.8)	12.0	(3.1)	S39	S. Pt. Roberts
2	48:51.5	123:08.7	15-Jan-81	1550:30	148	31.0	8.0	(25.8)			22.0	(71.0	1.0	(3.2)	S37	E. Mayne Is.
3	48:59.3	123:21.6	16-Jan-81	0915:30	180	230.0	138.0	(60.0)	13.0	(5.7)	43.0	(18.7)	36.0	(15.7)	S31	N.E. Galiano Is.
4	48:58.8	123:19.7	16-Jan-81	1232:45	62	79.0			43.0	(54.4)	19.0	(24.1)	17.0	(21.5)	S31	N.E. Galiano Is.
5	49:01.7	123:26.5	16-Jan-81	1424:28	172	163.0	100.0	(61.3)	19.0	(11.7)	38.0	(23.3)	6.0	(3.7)	S27	E. Porlier Pass
6	49:01.2	123:26.9	16-Jan-81	1558:30	273	264.0	200.0	(75.8)	15.0	(5.7)	49.0	(18.6)			S29	E. Porlier Pass
7	49:18.1	123:37.2	17-Jan-81	0840:30	63	69.0			67.0	(97.1)			2.0	(2.9)	S15	S. McCall Bank
8	49:19.8	123:39.0	17-Jan-81	0948:30	184	146.0	137.0	(93.8)	5.0	(3.4)			4.0	(2.7)	S15	S. McCall Bank
9	49:16.0	123:33.8	17-Jan-81	1230:30	83	426.0			397.0	(93.2)	22.0	(5.2)	7.0	(1.6)	S17	N.E. Gabriola Is.
10	49:14.7	123:33.1	17-Jan-81	1427:30	166	112.0	50.0	(44.6)	12.0	(10.7)	50.0	(44.6)			S17	N.E. Gabriola Is.
11	49:14.3	123:32.3	17-Jan-81	1602:33	245	198.0	126.0	(63.6)	4.0	(2.0)	56.0	(28.3)	12.0	(6.1)	S17	N.E. Gabriola Is.
12	49:53.3	124:53.5	21-Jan-81	0835:28	78	62.0	52.0	(83.9)	10.0	(16.1)					N29	W. Grant Reef
13	49:55.5	124:54.4	21-Jan-81	1100:30	77	201.0	162.0	(80.6)	10.0	(5.0)	29.0	(14.4)			N29	W. Grant Reef
14	49:52.8	124:42.2	21-Jan-81	1325:43	111	272.0	140.0	(51.5)	57.0	(21.0)	75.0	(27.6)			NA12	Powell River
15	49:50.5	124:34.9	22-Jan-81	0827:33	74	1,606.0	1,183.0	(73.7)	384.0	(23.9)	39.0	(2.4)			M1	Powell River
16	49:44.8	124:22.9	22-Jan-81	1046:29	129	79.0	40.0	(50.6)	30.0	(38.0)	9.0	(11.4)			M5	Malaspina Strait
17	49:44.7	124:21.5	22-Jan-81	1327:29	134	1,162.0	504.0	(43.4)	618.0	(53.2)	39.0	(3.4)	1.0	(0.1)	M5	Malaspina Strait
18	49:43.1	124:19.7	22-Jan-81	1505:28	257	392.0	353.0	(90.1)	2.0	(0.5)	33.0	(8.4)	4.0	(1.0)	M7	Malaspina Strait
19	49:32.4	124:06.5	22-Jan-81	1726:29	100	213.0	102.0	(47.9)	75.0	(35.2)	36.0	(16.9)			M13	Malaspina Strait
20	49:26.0	124:28.5	23-Jan-81	0822:28	228	95.0	32.0	(33.7)	1.0	(1.1)	61.0	(64.2)	1.0	(1.1)	N5	N. Sabine Chan.
21	49:38.0	124:29.2	23-Jan-81	1057:60	276	103.0	78.0	(75.7)	2.0	(1.9)	22.0	(21.4)	2.0	(1.9)	N13	N. Sabine Chan.
21 tows						6,286.0	3,735.0	(59.4)	1,802.0	(28.7)	645.0	(10.3)	105.0	(1.7)		

Appendix Table V/1B. Tow and catch information for the February survey. The sets were made by the ARCTIC HARVESTER.

Tow no.	Location	Track series	Date	Time		Depth		Total	Hake		Pollock		Dogfish	
				Start	Run	Top	Bot		Wt. (kg)	%	Wt. (kg)	%	Wt. (kg)	%
1	E. Gabriola	S	20 Feb 81	2010	30		183	387.0	292.0	75.5	15.0	3.9	80.0	20.7
2	E. Mayne Is.	S	21 Feb 81	0955	45	112		291.0	113.0	38.8	170.0	58.4	0.0	0.0
3	E. Mayne Is.	S	21 Feb 81	1140	45	141		527.0	342.0	64.9	159.0	30.2	12.0	2.3
4	E. Galiano Is.	S	21 Feb 81	1345	45		149	519.0	344.0	66.3	28.0	5.4	83.0	16.0
5	E. Galiano Is.	S	21 Feb 81	1537	40		225	663.0	494.0	74.5	88.0	13.3	66.0	10.0
6	E. Galiano Is.	S	21 Feb 81	1707	38		174	448.0	190.0	42.4	188.0	42.0	66.0	14.7
7	S. Sandheads	S	21 Feb 81	1907	30	138		280.0	30.0	10.7	214.0	76.4	32.0	11.4
8	W. Fraser R.	S	22 Feb 81	0732	18		173	1550.0	890.0	57.4	411.0	26.5	247.0	15.9
9	W. Fraser R.	S	22 Feb 81	0915	45	126		476.0	128.0	26.9	266.0	55.9	82.0	17.2
10	W. Fraser R.	S	22 Feb 81	1048	57	77		1824.0	0.0	0.0	188.0	10.3	1621.0	88.9
11	W. Fraser R.	S	22 Feb 81	1315	45		238	141.0	98.0	69.5	26.0	18.4	15.0	10.6
12	W. Fraser R.	S	22 Feb 81	1450	30	137		538.0	273.0	50.7	173.0	32.2	86.0	16.0
13	E. Gabriola Is.	S	22 Feb 81	1645	30		293	312.0	239.0	76.6	38.0	12.2	35.0	11.2
14	E. Gabriola Is.	S	22 Feb 81	1810	60	91		113.0	22.0	19.5	38.0	33.6	53.0	46.9
15	W. Burrard In.	S	23 Feb 81	0728	47	86		108.0	4.0	3.7	94.0	87.0	8.0	7.4
16	W. Burrard In.	S	23 Feb 81	0855	30		146	444.0	286.0	64.4	154.0	34.7	4.0	0.9
17	S.E. Halibut Bank	S	23 Feb 81	1025	25		183	1640.0	1587.0	96.8	23.0	1.4	30.0	1.8
18	S.E. Halibut Bank	S	23 Feb 81	1135	20		276	350.0	284.0	81.1	35.0	10.0	31.0	8.9
19	S. Halibut Bank	S	23 Feb 81	1340	30		356	609.0	431.0	70.8	37.0	6.1	101.0	16.6
20	S. Halibut Bank	S	23 Feb 81	1505	30		183	733.0	590.0	80.5	101.0	13.8	30.0	4.1
21	S. Halibut Bank	S	23 Feb 81	1620	30	128		190.0	134.0	70.5	27.0	14.2	29.0	15.3
22	S. McCall Bank	S	23 Feb 81	1825	50		146	166.0	103.0	62.0	36.0	21.7	27.0	16.3
24	N.E. Gabriola Is.	S	24 Feb 81	1045	45	86		64.0	11.0	17.2	27.0	42.2	24.0	37.5
25	N.E. Gabriola Is.	S	24 Feb 81	1215	45		150	750.0	398.0	53.1	224.0	29.9	128.0	17.1
26	N.E. Gabriola Is.	S	24 Feb 81	1420	45		201	590.0	446.0	75.6	57.0	9.7	87.0	14.7
27	N.E. Gabriola Is.	S	24 Feb 81	1605	22		274	519.0	359.0	69.2	72.0	13.9	88.0	17.0
28	N.E. Gabriola Is.	S	24 Feb 81	1735	35		348	451.0	285.0	63.2	59.0	13.1	107.0	23.7
29	N.E. Gabriola Is.	S	24 Feb 81	2235	30	91		87.0	27.0	31.0	46.0	52.9	14.0	16.1
30	N.E. Gabriola Is.	S	24 Feb 81	2340	30		150	1121.0	991.0	88.4	77.0	6.9	53.0	4.7
31	N.E. Gabriola Is.	S	25 Feb 81	0100	30		201	677.0	491.0	72.5	131.0	19.4	55.0	8.1
32	N.E. Gabriola Is.	S	25 Feb 81	0240	35		274	535.0	351.0	65.6	109.0	20.4	75.0	14.0
33	N.E. Gabriola Is.	S	25 Feb 81	0410	30		343	542.0	341.0	62.9	65.0	12.0	136.0	25.1

Appendix Table V/18 (cont'd)

Tow				Time	Depth			Hake		Pollock		Dogfish	
34	S. Thormanby Is.	S	25 Feb 81	1510 : 60	91		153.0	37.0	24.2	93.0	60.8	20.0	13.1
35	S. Thormanby Is.	S	25 Feb 81	1650 : 45		201	720.0	623.0	86.5	22.0	3.1	75.0	10.4
36	S. Sechelt Pen.	S	25 Feb 81	1945 : 35		185	304.0	282.0	92.8	5.0	1.6	17.0	5.6
37	Malaspina St.	M	26 Feb 81	0708 : 35		198	319.0	289.0	90.6	6.0	1.9	24.0	7.5
38	Malaspina St.	M	26 Feb 81	1020 : 35		193	421.0	391.0	92.9	3.0	0.7	25.0	5.9
39	Malaspina St.	M	26 Feb 81	1235 : 50	110		69.0	1.0	1.4	49.0	71.0	15.0	21.7
40	Malaspina St.	M	26 Feb 81	1315 : 30		256	615.0	381.0	62.0	195.0	31.7	34.0	5.5
41	Malaspina St.	M	26 Feb 81	2055 : 30		201	361.0	318.0	88.1	1.0	0.3	33.0	9.1
42	Malaspina St.	M	26 Feb 81	2240 : 35	140		482.0	422.0	87.6	1.0	0.2	58.0	12.0
43	Malaspina St.	M	27 Feb 81	0030 : 45	110		74.0	23.0	31.1	12.0	16.2	39.0	52.7
44	Malaspina St.	M	27 Feb 81	0755 : 35		183	262.0	247.0	94.3	0.0	0.0	15.0	5.7
45	Malaspina St.	M	27 Feb 81	0937 : 33		267	607.0	585.0	96.4	1.0	0.2	17.0	2.8
46	W. Grant Reef	N	27 Feb 81	1210 : 35		152	800.0	765.0	95.6	4.0	0.5	31.0	3.9
47	W. Grant Reef	N	27 Feb 81	1350 : 45		201	1891.0	1887.0	99.8	4.0	0.2	0.0	0.0
48	W. Grant Reef	N	27 Feb 81	1535 : 35		278	833.0	778.0	93.4	2.0	0.2	43.0	5.2
49	Sutil Chan.	N	28 Feb 81	0745 : 23	91		760.0	731.0	96.2	15.0	2.0	14.0	1.8
50	Sutil Chan.	N	28 Feb 81	0920 : 30		201	188.0	113.0	60.1	1.0	0.5	75.0	39.9
51	W. Mittlenatch Is.	N	28 Feb 81	1123 : 30		183	326.0	232.0	71.2	1.0	0.3	93.0	28.5
52	S. Montgomery Bank	N	28 Feb 81	1313 : 15		165	1314.0	803.0	61.1	1.0	0.1	511.0	38.9
53	W. Texada Is.	N	28 Feb 81	1558 : 60	91		58.0	5.0	8.6	53.0	91.4	0.0	0.0
54	W. Texada Is.	N	28 Feb 81	1735 : 45		183	124.0	99.0	79.8	7.0	5.6	18.0	14.5
55	W. Texada Is.	N	28 Feb 81	1920 : 33		238	456.0	439.0	96.3	5.0	1.1	17.0	3.7
56	Sabine Chan.	SA	01 Mar 81	0735 : 32	96		170.0	28.0	16.5	120.0	70.6	22.0	12.9
57	Sabine Chan.	SA	01 Mar 81	0915 : 30		187	381.0	342.0	89.8	10.0	2.6	29.0	7.6
58	Sabine Chan.	SA	01 Mar 81	1123 : 32		254	519.0	506.0	97.5	1.0	0.2	11.0	2.1
59	Sabine Chan.	SA	01 Mar 81	1240 : 30	0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
60	W. Lasquiti Is.	N	01 Mar 81	1540 : 30		183	166.0	107.0	64.5	5.0	3.0	54.0	32.5
61	W. Lasquiti Is.	N	01 Mar 81	1700 : 50		256	189.0	124.0	65.6	4.0	2.1	61.0	32.3
62	S. Lasquiti Is.	N	01 Mar 81	1920 : 45		175	99.0	97.0	98.0	2.0	2.0	0.0	0.0
63	N. Horswell Chan.	S	02 Mar 81	0700 : 30		201	271.0	213.0	78.6	2.0	0.7	58.0	21.4
64	N. Horswell Chan.	S	02 Mar 81	0825 : 40		256	226.0	167.0	73.9	14.0	6.2	45.0	19.9
65	N.E. Ballenas Is.	S	02 Mar 81	1035 : 60	91		49.0	14.0	28.6	20.0	40.8	15.0	30.6

Appendix Table V/18 (cont'd)

Tow no.	Location	Track series	Date	Time	Depth		Total	Hake		Pollock		Dogfish	
				Start : Run	Top	Bot		Wt. (kg)	%	Wt. (kg)	%	Wt. (kg)	%
66	N.E. Ballenas Is.	S	02 Mar 81	1210 : 35		183	223.0	182.0	81.6	9.0	4.0	32.0	14.3
67	S.E. Texada Is.	S	02 Mar 81	1350 : 26		201	301.0	254.0	84.4	14.0	4.7	26.0	8.6
68	S.E. Texada Is.	S	02 Mar 81	1510 : 35		256	261.0	209.0	80.1	11.0	4.2	41.0	15.7
69	S.E. Texada Is.	S	02 Mar 81	1630 : 65	96		196.0	26.0	13.3	147.0	75.0	20.0	10.2
70	Malaspina St.	M	02 Mar 81	1855 : 38		189	463.0	408.0	88.1	11.0	2.4	29.0	6.3
71	Merry Is.	S	03 Mar 81	0755 : 30		165	977.0	916.0	93.8	44.0	4.5	14.0	1.4
72	Merry Is.	S	03 Mar 81	0915 : 45	91		75.0	26.0	34.7	33.0	44.0	16.0	21.3
73	Merry Is.	S	03 Mar 81	1040 : 30		238	297.0	214.0	72.1	53.0	17.8	30.0	10.1
Total							33645.0	23858.0	70.9	4357.0	12.9	5182.0	15.4

Appendix Table V/1C. Tow and catch information for the April survey. The sets were made by the G.B. REED.

Tow no.	Lat.	Long.	Date	Time Start:Run	Depth	Catch total	Hake Wt (kg)	Hake %	Pollock Wt (kg)	Pollock %	Dogfish Wt (kg)	Dogfish %	Other Wt (kg)	Other %	Transect
1	49:34.5	124:22.8	16-Apr-81	1629:45	113	899.9	841.4	(93.5)	24.0	(2.7)	32.0	(3.6)	2.5	(0.3)	SA09 Sabine Chan.
2	49:27.8	124:23.8	16-Apr-81	1902:30	71	774.0	640.0	(82.7)	79.0	(10.2)	55.0	(7.1)			N05 Stevens Passage
3	49:53.5	125:01.2	17-Apr-81	0815:29	110	1,366.9			1,330.9	(97.4)	36.0	(2.6)			N31 N. Georgia Straits
4	49:49.6	124:54.6	17-Apr-81	1019:36	121	156.0	0.5	(0.3)	146.0	(93.6)	9.5	(6.1)			N27 N. Georgia Straits
5	49:43.2	124:39.0	17-Apr-81	1255:32	132	588.0	2.0	(0.3)	545.0	(92.7)	38.0	(6.5)	3.0	(0.5)	N19 N.W. Texada Island
6	49:44.6	124:40.2	17-Apr-81	1437:34	165	64.5	8.5	(13.2)	28.0	(43.4)	28.0	(43.4)			N19 N.W. Texada Island
7	49:40.1	124:31.1	17-Apr-81	1621:33	124	745.4	125.0	(16.8)	569.4	(76.4)	51.0	(6.8)			N13 Gilles Bay
8	49:27.2	124:36.7	17-Apr-81	1903:29	91	279.0	199.5	(71.5)	26.0	(9.3)	53.5	(19.2)			N09 S. Hornby Island
9	49:21.1	124:15.4	18-Apr-81	0820:36	126	680.0	637.0	(93.7)	29.0	(4.3)	12.2	(1.8)	1.8	(0.2)	N01 E. Parksville
10	49:22.4	124:15.9	18-Apr-81	0952:30	201	168.0	143.5	(85.4)	2.0	(1.2)	22.0	(13.1)	0.5	(0.3)	S01 E. Parksville
11	49:35.0	124:06.9	18-Apr-81	1257:28	201	141.0	104.0	(73.8)	6.0	(4.3)	31.0	(22.0)			M13 Malaspina Strait
12	48:50.6	123:01.0	21-Apr-81	0900:30	73	133.7	15.0	(11.2)	19.0	(14.2)	4.5	(3.4)	95.2	(71.2)	S41 E. Saturna Island
13	48:52.4	123:13.1	21-Apr-81	1115:36	153	295.5	166.0	(56.2)	24.0	(8.1)	85.0	(28.8)	20.5	(6.9)	S39 E. Saturna Island
14	48:57.6	123:17.4	21-Apr-81	1256:30	170	569.0	412.5	(72.5)	10.0	(1.8)	118.0	(20.7)	28.5	(5.0)	S33 W. Pt. Roberts
15	49:02.3	123:28.2	21-Apr-81	1505:30	201	228.0	211.0	(92.5)	1.0	(0.4)	14.0	(6.1)	2.0	(0.9)	S27 Porlier Pass
16	49:00.8	123:31.7	21-Apr-81	1730:30	77	119.5	10.0	(8.4)	28.0	(23.4)	81.0	(67.8)	0.5	(0.4)	S27 Porlier Pass
17	49:06.6	123:36.0	22-Apr-81	0823:26	91	2,168.2	2,115.2	(97.6)	20.0	(0.9)	27.0	(1.2)	6.0	(0.3)	S23 Thrasher Rock
18	49:10.2	123:33.0	22-Apr-81	1122:32	194	645.5	616.0	(95.4)	9.5	(1.5)	16.0	(2.5)	4.0	(0.6)	S21 Thrasher Rock
19	49:18.0	123:36.9	22-Apr-81	1425:30	183	128.5	124.5	(96.9)	2.0	(1.6)	1.0	(0.8)	1.0	(0.8)	S15 McCall Bank
20	49:23.1	123:57.5	22-Apr-81	1716:31	201	123.0	95.0	(77.2)	5.0	(4.1)	13.0	(10.6)	10.0	(8.1)	S07 Mincheisea
21	49:22.6	123:56.8	22-Apr-81	1833:29	100	47.5	9.0	(18.9)	26.0	(54.7)	12.0	(25.3)	0.5	(1.0)	S07 Mincheisea
22	49:20.0	124:10.6	23-Apr-81	0822:32	119	667.3	633.3	(94.9)	7.5	(1.1)	23.0	(3.4)	2.5	(0.5)	S01 E. Parksville
23	49:15.0	123:51.2	23-Apr-81	1234:13	119	1,390.17	1,570.7	(98.7)	11.0	(0.7)	9.0	(0.6)			S11 Gabriola Island
23 tows						12,579.1	8,679.6	(69.0)	2,948.3	(23.4)	771.7	(6.1)	179.5	(1.4)	

Appendix Table V/2. Species ratios are derived from the tow information and are given for each of the three cruises. The first column indicates the tows that were used for each area. The "fraction" is normalized to the hake, pollock, and "other" catch excluding dogfish. The range of headline depth is given. For GBR81-1 any set above 120 m is used for the "top layer". For the remaining cruises this cutoff is at 145 m.

Table V/2A. GBR81-1 Species Ratios as Determined from Tows

GBR81-1 Tow no.	Transect top or bottom layer		Net depth (m)	Catch (kg) H+P+O	Species fractions				
					Hake	Pollock	Other	Dogfish	Sum
1-21	All		62-276	5641	.662±.078	.319±.079	.019±.010	.114±.038	1.114
1,4,7,9,12,13 14,15,19	All	T	62-111	3088	.638±.116	.350±.112	.012±.009	.072±.036	1.072
2,3,5,6,8,10,11 16,17,18,20,21	All	B	129-276	2553	.692±.123	.282±.134	.026±.018	.165±.070	1.070
1,4,7,9	S	T	62-103	913	.361±.309	.597±.311	.042±.023	.048±.029	1.048
2,3,5,6,8,10,11	S	B	148-273	886	.857±.038	.077±.019	.067±.035	.291±.075	1.291
12,13	N	T	77-78	234	.915±.040	.085±.040	0	.124±.066	1.124
20,21, use all B	N	B	228-276	116	.948±.004	.026±.002	.026±.002	.716±.632	1.716
14	NA	T	111	197	.711	.289	0	.381	1.381
Use all B	NA	B							
15,19	M	T	74-100	1744	.737±.033	.263±.033	0	.043±.033	1.043
16,17,18	M	B	129-257	1551	.578±.162	.419±.165	.003±.003	.059±.020	1.059
Use all T	SA	T							
Use all B	SA	B							

Appendix Table V/28. GBR81-2 Species Ratio as Determined from ARCTIC HARVESTER Tows.

Arctic Harvester tow no.	Transect top or bottom layer		Net depth (m)	Catch (kg) H+P+O	Species fractions				
					Hake	Pollock	Other[1]	Dogfish	Sum
1-58, 60-73	All		77-356	28215	.846	.154	0	.184	1.184
(3)	All	T	77-141	4342	.552	.448	0	.519[2]	1.519
Exclude #10 from above			86-141					.146	1.146
(4)	All	B	146-356	23873	.899	.101	0	.123	1.123
2,3,7,9,10,12 14,15,21,24,29 34,65,69,72	S	T	77-141	2882	.412±.078	.588±.078	0	.705±.469	1.469
Exclude #10 from above			86-141	2694	.441±.074	.559±.074	0	.153±.037	1.153
1,4,5,6,8,11,13 16-20,22,25-28 30-33,35,36,63 64,66-68,71,73	S	B	146-356	14698	.854±.028	.146±.028	0	.128±.020	1.128
49,53	N	T	91	804	.915±.120	.085±.120	0	.017±.003	1.017
46,47,48,50,51 52,54,55,60,61,62	N	B	152-278	5480	.993±.003	.007±.003	0	.165±.099	1.165
	NA	T	use	M T					
	NA	B	use	M B					
39,42,43	M	T	110-140	508	.878±.161	.122±.161	0	.220±.114	1.220
37,38,40,41,44 45,70	M	B	183-267	2836	.923±.063	.077±.063	0	.062±.009	1.062

Appendix Table V/28 (cont'd)

Arctic Harvester Tow no.	Transect top or bottom layer		Net depth (m)	Catch (kg) H+P+O	Species fractions				
					Hake	Pollock	Other	Dogfish	Sum
	SA	T	use	N T					
	SA	B	use	N B					

(1) The catch of "other species" was small and has been ignored.
(2) This large fraction for dogfish is caused by a single large catch of dogfish from tow 10.
(3) 2,3,7,9,10,12,14,15,21,24,29,34,39,42,43,49,53,56,65,69,72.
(4) 1,4,5,6,8,11,13,16-20,22,25-28,30-33,35-38,40,41,44-48,50-52,54,55,57,58,60-64,66-68,70-73.

Appendix Table V/2C. GBR81-4 Species Ratio as Determined from Tows

GBR81-4 Tow no.	Transect top or bottom layer		Net depth (m)	Catch (kg) H+P+O	Species fractions				
					Hake	Pollock	Other	Dogfish	Sum
12,16,17,21,22,23	S	T	73-119	4569.4	.953±.036	.024±.014	.023±.026	.034±.025	1.034
10,13,14,15,18 19,20	S	B	153-201	1888.5	.936±.026	.028±.012	.035±.016	.142±.062	1.142
2,3,4,5,7,8,9	N	T	71-132	4334.1	.370±.194	.629±.195	.001±.001	.059±.017	1.059
6	N	B	165	36.5	.233	.767	0	.767	1.767
-	NA	T	-	use all T					
-	NA	B	-	use all B					
-	M	T	-	use all T					
11	M	B	201	110	.945	.055	0	.282	1.282
1	SA	T	113	867.9	.969	.028	.003	.037	1.037
-	SA	B	-	use all B					
1-23	All		71-201	11806.4	.735±.119	.250±.119	.015±.009	.065±.019	1.065
1,2,3,4,5,7,8, 9,12,16,17,21, 22,23	All	T	71-132	9771.4	.696±.146	.293±.146	.011±.011	.045±.015	1.045
6,10,11,13,14,15, 18,19,20	All	B	153-201	2035.0	.924±.028	.043±.020	.033±.014	.161±.060	1.161

Appendix Table V/3. Mean fork lengths (cm) and standard deviations of hake, pollock, and dogfish for the tows made during GBR81-1.

Tow	Hake		Pollock		Dogfish	
#	$\bar{L}$	N	$\bar{L}$	N	$\bar{L}$	N
1	48.7±3.9	183	42.1±7.6	52	-	-
2	-	-	-	-	-	-
3	44.4±5.0	179	-	-	-	-
4	-	-	40.4±2.1	72	-	-
5	-	-	-	-	-	-
6	37.5±4.9	113	-	-	-	-
7	-	-	40.8±2.7	117	-	-
8	40.2±7.5	270	-	-	-	-
9	-	-	-	-	-	-
10	-	-	-	-	-	-
11	-	-	-	-	-	-
12	43.8±3.3	91	42.2±3.0	15	-	-
13	44.1±3.7	320	41.3±3.0	18	-	-
14	38.0±8.3	225	42.9±3.3	76	80.7±13.6	29
15	40.7±3.2	191	40.2±2.6	333	-	-
16	-	-	39.4±2.2	56	-	-
17	40.8±3.6	202	40.6±2.7	166	-	-
18	40.3±5.1	103	-	-	-	-
19	44.7±3.0	92	40.4±2.7	67	-	-
20	41.4±8.1	68	-	-	37.4±3.4	146
21	36.5±7.3	106	-	-	48.8±14.6	38
Total	41.4±6.4	2352	40.7±7.9	972	45.9±16.4	213

POOR

QUALITY

ORIGINAL